Technological Progress and Rent Seeking*

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Abstract

We model firms' allocation of resources between surplus-creating (a.k.a., productive) and surplus-appropriating (a.k.a., rent-seeking) activities. We show that industry- or economy-wide technological progresses, such as the recent improvements in processing big data, induce a disproportionate and socially inefficient allocation of resources towards surplus appropriation, even when the associated productivity gains are far larger for surplus-creating activities than for surplus-appropriating activities. As technology improves, firms lean more on rent seeking to obtain their profits, endogenously reducing the impact of technological progress on economic progress and inflating the price of resources that are used for both types of activities.

Keywords: Resource Allocation, Big Data, Surplus Appropriation, Economic Growth.
JEL Classifications: D21, D24, O33, O41

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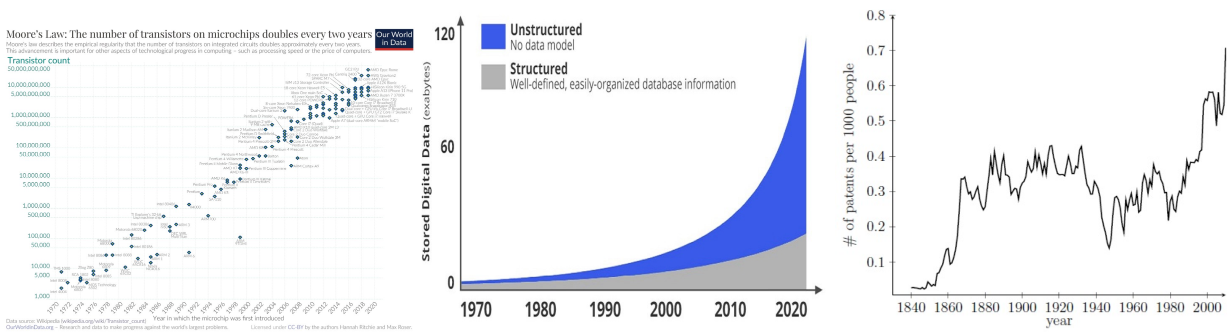
1 Introduction

The last few decades have featured exceptional technological progress. Just to give a few examples, we witnessed striking growth in computer processing power, data availability, and patented innovation (see Figure 1). Standard growth theories highlight the importance of technological progress that improves firms' productivity in generating long-term economic growth. Technological advancements embodied in capital (such as improvement of materials, robotization, automation, etc), in labor (higher human capital and knowledge), in methods used to combine inputs (organizational and human resource managements), and in the creation of new varieties of intermediate goods (allowing for a more complex final output), can all promote the growth of an economy. It is thus surprising that U.S. economic growth has slowed down in recent decades (see Table 1).



(a) Transistors per microchip **(b)** Stored digital data **(c)** U.S. patents, scaled per capita

Figure 1
Technological growth. Panel (a) plots the exponential growth in computer processing power, as measured by the number of transistors included in various types of microchips (adapted from Roser and Ritchie 2013). Panel (b) plots the explosion in stored digital data (adapted from Durant 2020). Panel (c) plots the number of U.S. patents scaled per capita (adapted from Kelly et al. 2020).

Omitted from the academic discussion on growth and technology is the impact of technological advancements on the rent-seeking behaviors of agents in the economy. In this paper, we model firms' optimal allocation of resources between surplus-creating (i.e., productive) and surplus-appropriating (i.e., rent-seeking) activities to uncover the impact of technological progress on firms' incentives to use improved technologies to appropriate other firms' surpluses. We show

Table 1
Real U.S. GDP growth per decade.

Decade	Avg. U.S. real GDP growth per year
1951-1960	3.64%
1961-1970	4.29%
1971-1980	3.19%
1981-1990	3.34%
1991-2000	3.45%
2001-2010	1.78%
2011-2020	1.64%

Data Source: Federal Reserve Economic Data website (https://fred.stlouisfed.org/series/GDPC1)

that a technological breakthrough that improves productivity in an entire industry generically induces a disproportionate and socially inefficient allocation of resources to surplus-appropriating activities. While this prediction would be trivial if restricted to technological improvements that affect surplus-appropriating tasks, it holds even when the productivity gains from technological progress are far larger for surplus-creating activities than for surplus-appropriating activities. In fact, as long as technological progress ameliorates *to some extent* firms' ability to appropriate their rivals' surplus, firms respond to this progress by shifting a larger share of their resources towards this type of activities.

When a technological improvement increases total economic surplus, firms' incentives to perform rent-seeking activities are amplified. Put simply, it is more tempting to work towards appropriating the surplus from others when others have a larger surplus to appropriate. Industry-wide technological innovations that improve a firm's abilities to create as well as appropriate economic surplus, to different extents, will cause a firm's incentives to appropriate others' surplus to increase disproportionately more than its incentives to create additional surplus. And as technology keeps improving, the economy gradually moves from a *productive* economy to a *rent-seeking* economy, in which any technological advancement translates less into higher output. Due to this overinvestment in surplus-appropriating activities, aggregate output is a concave, potentially non-monotone function of technology.

Our analysis also sheds light on the impact of this inefficient allocation of resources on their price. As technology improves, and the economy moves towards a rent-seeking economy, the disproportionate allocation of resources to non-productive activities can raise the price of resources above what it would be in a benchmark economy without rent seeking. In this sense, the consequences of technological advancements for the economy do not only manifest themselves in a higher share of the economy's resources being inefficiently allocated to rent-seeking activities, but also in larger prices paid for the resources needed to perform these activities (which often happen to be the same kind of resources that are used to create social surplus).

Even though the expression "rent seeking" is sometimes used to specifically refer to lobbying activities and the interactions of agents with a public authority, our analysis is more general as it encompasses any activity aimed at appropriating the surplus of other agents, thereby generating a wedge between the private and social marginal value of this activity. Central to our analysis is that these activities become more attractive as the rest of the economy performs better, and the surplus that can be appropriated gets larger.

Recent technological waves led by improvements in data collection, storage, processing, transportation and communication have improved dramatically the use of information, not only facilitating the creation of surplus but also its appropriation by others. For example, better technologies can now be used both to innovate, through research and development, and to imitate other firms' innovations. Big data, machine learning, and artificial intelligence have sped up and enhanced the creation of new drugs and material. However, these technological advances have also sped up and enhanced the ability to reverse engineer and copy rivals' innovations. Legal services, tax reporting services, and lobbying efforts are additional examples of economic activities that typically focus on redistributing surplus across agents. Our model suggests that as long as technological improvements increase the efficiency of these activities, then a disproportionate amount of resources will be allocated to them. The finance industry is also a setting where our insights can apply. Big data processing not only improved the allocation of credit and the monitoring of funded projects, which generate a more efficient use of idle capital, but it also facilitated various speculative activities, such as high-frequency trading in centralized stock markets. Again, our model suggests an over-investment of resources in the latter type of activities and an inflated price needed to acquire the relevant resources. As part of our analysis, we explore how our insights can be applied to these various types of surplus-appropriating activities and shed light on their rising popularity over the last few decades.

Our prediction of disproportionate investments of resources in strategies of surplus appropriation, even if technology facilitates surplus creation in a much stronger way, does not only apply to the recent informational revolution across the globe. It also speaks to the impact of earlier technological improvements on economic growth: agricultural and farming technologies that led to wars and invasions, industrial technologies that induced a revolution on services destined to redistribution of resources, transportation technologies that facilitated trading but also an expansion of speculative activities, communication technologies that facilitated logistics, but also that opened the doors to new appropriation activities. Our paper's insights point towards an understudied dampening effect of surplus appropriation in the relationship between technological progress and economic progress. As this dampening effect grows with technology over long periods of time, our paper highlights the heightened relevance of identifying, regulating, taxing, and/or curbing rent-seeking activities.

Literature review. Our paper contributes to the literature connecting technological improvements with economic growth. In the celebrated growth model of Solow (1957), long-term economic growth, in the balance-growth path, is purely driven by the growth rate of productivity, determined by technological improvements. Our work suggests that the connection between technological improvements and economic growth becomes weaker over time in the presence of rent-seeking opportunities. In this sense, rent seeking should be added to other elements commonly identified in the literature (e.g., Barro 1999) as part of the Solow residual, such as spillovers, increasing returns, taxes, and various types of factor inputs.

Recent research has focused on the effects of technological improvements in the collection, processing, and management of big data. Farboodi and Veldkamp (2020) show how information technology has led traders to focus on acquiring information about others' trades rather than about assets' fundamental values. Farboodi and Veldkamp (2021) discuss the importance of data accumulation on many firms' production process, generating a data feedback loop in which more data makes a firm more productive, generating more transactions and, as a result, more data. While none of these papers analyze the combination of technology, rent seeking, and economic growth like our paper does, they highlight the importance of understanding the nuances of new information technologies and their role in promoting economic growth.

Our paper provides novel insights for our understanding of surplus-appropriating activities. The seminal analysis by Murphy, Shleifer, and Vishny (1991) study the occupational choice of agents between productive and rent-seeking sectors, highlighting how this choice depends on the returns to ability and scale in each sector. When the returns from rent seeking are increasing in the intensity of rent-seeking activities, multiple equilibria might exist and agents' occupational choices may lead to lower growth, a channel that is further highlighted in Murphy, Shleifer, and Vishny (1993). While these papers already make the case that rent seeking slows economic growth, our work differs in several dimensions. While they study a worker's occupational choice, we instead study a firm's choice of how to allocate resources. This distinction allows our model to feature an intensive margin not present in models of occupational choice: all agents in our model (i.e., firms) can both create and appropriate surplus from others. Moreover, whereas these papers assume no technological progress in rent seeking, our paper shows how a small increase in the productivity of rent-seeking activities can disrupt the mapping of technological improvements and growth.

Our insights about the high price of resources when surplus appropriation becomes prevalent also relate our paper to the literature on the compensation of superstars, which identifies conditions under which the prices of production factors may seem to be excessive (see, e.g., Rosen 1981).

While our model does not specifically target one sector of the economy to generate this result, it can be used to understand why Greenwood and Scharfstein (2013) observe positive trends in the relative economic importance of the financial sector, including activities that would fit our description of surplus appropriation, while Philippon and Reshef (2012) and Célérier and Vallée (2019) observe large increases in the prices paid for an essential resource in this sector: workers.[1] Philippon (2010), Glode, Green, and Lowery (2012), Fishman and Parker (2015), Glode and Lowery (2016), and Berk and van Binsbergen (2021) already propose models in which resources are invested in financial activities that do not benefit society, but our paper shows how the scale and compensation associated with these activities might have been driven by firms' optimal re-allocation of resources in response to waves of technological innovations.

Another related literature studies the optimal taxation of revenues that may be produced by economic activities that generate negative externalities, like rent seeking in our model. Lockwood, Nathanson, and Weyl (2017) measure the negative externalities across several sectors, and conclude that rent-seeking behaviors are particularly prominent in the financial and legal sectors. Their evidence is cited by Rothschild and Scheuer (2016) to justify adjusting taxation schemes to account for rent-seeking externalities that may reallocate talent inefficiently (see also Scheuer and Slemrod 2021, for a discussion specifically focused on the role played by a wealth tax). Our analysis highlight how technological innovation amplifies the negative impact of rent-seeking activities on economic growth, thereby increasing the importance of designing policies that curb the inefficient allocation of resources.

Finally, an important discussion about rent seeking has focused on activities that relate to obtaining favors or privileges from the public sector. An example of this behavior is the large lobbying sector and its effects on segmented labor markets through public sector employment, as highlighted by Gelb, Knight, and Sabot (1991). We show that our paper's insights easily extend to the presence of a public sector, with firms disproportionately allocating resources to lobbying activities

[1] See Zingales (2015) for arguments consistent with the idea that some (but not all) financial activities fit our definition of surplus appropriation, a.k.a., rent seeking.

that become more beneficial as the economy becomes larger, and as such the public sector too.

In the next section, we introduce the environment of our model in which firms must decide how to allocate their resources between surplus-creating and surplus-appropriating activities. We show how this allocation of resources is impacted by industry-wide technological progress in Section 3. We also highlight the effects of the reallocation on the price of resources and on the aggregate economic output. We show that our main insights survive various extensions to our baseline model in Section 4 and we apply our paper's main insights to popular examples of rent-seeking activities in Section 5. The last section concludes.

2 Model

Suppose each firm $i \in I$ has a positive supply b_i of resources, from which the firm can choose to allocate a quantity $s_i \geq 0$ to *create (social) surplus* according to a production function $\pi_i(s_i)$, and allocate a quantity $x_i \geq 0$ to *appropriate surplus* by extracting a fraction $\alpha_i(x_i) \in [0,1]$ of a rival firm's surplus, such that $s_i + x_i \leq b_i$. (To fix ideas, it might help to think of these resources as labor, and each firm chooses how to allocate their workforce between the two types of activities.) For simplicity, assume for now that firm i has a single rival $j \neq i$ from which it can appropriate surplus, and vice-versa. Firm i's payoff is then given by:

$$\pi_i(s_i) \cdot [1 - \alpha_j(x_j)] + \pi_j(s_j) \cdot \alpha_i(x_i). \tag{1}$$

For now, the only restrictions we impose on the model is that, for all $i \in I$, $\pi_i(\cdot)$ and $\alpha_i(\cdot)$ are increasing, concave functions and $\alpha_i(\cdot) \in [0,1]$.

Firm i finds it optimal to allocate its resources to satisfy the first-order condition:

$$\pi_i'(s_i) \cdot [1 - \alpha_j(x_j)] = \pi_j(s_j) \cdot \alpha_i'(x_i), \tag{2}$$

where $s_i + x_i = b_i$. In order to capture technological progress, we assume here that each firm's production function $\pi_i(\cdot)$ and $\alpha_i(\cdot)$ can be decomposed into a firm-specific technological parameter and a concave function of the resources the firm invests in that specific activity. That is, we let $\pi_i(s_i) \equiv \phi_{y,i} \cdot y(s_i)$ and $\alpha(x_i) \equiv \phi_{a,i} \cdot a(x_i)$. This is the same as assuming that increases in productivity comes from a technological change improving *total factor productivity*. We will show, in Section 4, that our insights also apply to a *factor-augmenting* technological change as long as production functions follow a standard Cobb-Douglas specification.

Given the assumed production functions, the firm's first-order condition becomes:

$$\phi_{y,i} \cdot y'(s_i) \cdot [1 - \phi_{a,j} \cdot a(x_j)] = \phi_{y,j} \cdot y(s_j) \cdot \phi_{a,i} \cdot a'(x_i). \quad (3)$$

This first-order condition delivers intuitive implications. Ceteris paribus (including keeping firm j's actions fixed), when firm i becomes individually more productive in creating surplus (i.e., $\phi_{y,i}$ increases), firm i finds it optimal to allocate more resources towards surplus-creating activities. When instead firm i becomes individually more productive in appropriating surplus from the other firm (i.e., $\phi_{a,i}$ increases), it finds it optimal to allocate more resources towards surplus-appropriating activities. Together, we get the natural implication that each firm responds to a firm-specific technological advancement by tilting its allocation of resources towards the activities whose productivity benefits most from the advancement. Again, this logic holds in partial equilibrium and in response to individual improvements in technology. In the following sections, we will study what happens when firms are hit simultaneously by an industry-wide technological advancement, and highlight the consequences of technological progress in general equilibrium.

3 Industry-Wide Technological Progress

We now investigate how firms' resource allocation is impacted by technological progress that affects a firm and its rival(s) equally. In contrast to the earlier analysis, we will now account for the fact that, in equilibrium, a firm has to react to the best response of its rival(s). In particular, we set $\phi_{a,i} = \phi_{a,j} \equiv \phi_a$ and $\phi_{y,i} = \phi_{y,j} \equiv \phi_y$. With these industry-wide parameters, we can simplify firm i's first-order condition to:

$$y'(s_i) \cdot [1 - \phi_a \cdot a(x_j)] = y(s_j) \cdot \phi_a \cdot a'(x_i). \tag{4}$$

Interestingly, the industry-wide productivity parameter associated with surplus creation, ϕ_y, disappears from the first-order condition. Thus, the optimal allocation of resources is unaffected by any industry-wide improvement in the productivity of firms' surplus-creating activities. The reason for this is that this type of technological progress boosts a firm's rewards to surplus creation in the same proportion it boosts the rewards from appropriating its rival's (now larger) surplus.

On the other hand, the industry-wide productivity of surplus-appropriating activities, ϕ_a, still enters the first-order condition. Ceteris paribus, a higher ϕ_a means that the left-hand side of (4) is lower while the right-hand side is higher. Therefore, firm i's optimal allocation of resources requires a smaller s_i and a larger x_i in response to a boost in ϕ_a. Any technological progress that increases the productivity of surplus-appropriating activities results in a larger share of the firm's resources being allocated to surplus appropriation (even if the technological progress also boosts the productivity of surplus-creating activities).

3.1 Allocation of resources

While predicting a firm's response to a change in industry-wide productivity levels is easy when holding its rival's allocation of resources fixed, what happens in equilibrium is not as immediate. Since firm i is expected to tilt its allocation of resources more towards surplus appropriation in response to any technological progress that boosts ϕ_a, regardless of how it affects ϕ_y, the benefit to firm j to produce its own surplus might decrease even though ϕ_y increases. On the other hand, the effect of this technological progress on the marginal benefit of appropriating firm i's surplus combines a decrease in resources invested by firm i with a higher productivity per unit invested.

To understand how all these effects combine in equilibrium, we now solve for a symmetric equilibrium by considering any pair of symmetrically-impacted and behaving firms. Dispensing from the sub-indices i and j, equation (4) can then be re-written as:

$$y'(b-x^*)\cdot[1-\phi_a\cdot a(x^*)]-y(b-x^*)\cdot\phi_a\cdot a'(x^*)=0. \tag{5}$$

If we differentiate the left-hand side of the first-order condition in (5) by x^*, we get:

$$-y''(b-x^*)\cdot[1-\phi_a\cdot a(x^*)]-y(b-x^*)\cdot\phi_a\cdot a''(x^*), \tag{6}$$

which is strictly positive whenever $a(\cdot)$ is strictly concave or $y(\cdot)$ is strictly concave and $\alpha(x^*)$ (i.e., $\phi_a\cdot a(x^*)$) remains a fraction smaller than 1. Thus, under fairly standard assumptions, the first-order condition in (5) can only be satisfied with one level of x^* and, as a result, there exists only one symmetric equilibrium.

As explained above, the allocation of resources between surplus-creating and surplus-appropriating activities only depends on the absolute productivity of the latter (i.e., ϕ_a), regardless of the level of the former (i.e., ϕ_y). By applying the implicit function theorem to the first-order condition in (5), we can solve for how a marginal change in ϕ_a would affect the equilibrium investment in surplus appropriation x^*:

$$\frac{\partial x^*}{\partial\phi_a}=-\frac{y'(b-x^*)\cdot a(x^*)+y(b-x^*)\cdot a'(x^*)}{y''(b-x^*)\cdot[1-\phi_a\cdot a(x^*)]+y(b-x^*)\cdot\phi_a\cdot a''(x^*)}. \tag{7}$$

This expression is strictly positive whenever $a(\cdot)$ is strictly concave or $y(\cdot)$ is strictly concave and $\alpha(x^*)$ remains a fraction smaller than 1. Thus, under the same fairly standard assumptions as above, technological progress is expected to lead to more (socially inefficient) investment of resources in surplus appropriation. Yet, the surplus created by each firm, i.e., $\pi(s^*) = \phi_y \cdot y(s^*)$, might still increase with technological progress that significantly improves the productivity of surplus-creating activities, ϕ_y. We will revisit these implications in subsection 3.4 by parameterizing the model using simple functional forms.

3.2 Price of resources

Now, we assume that firms have to compete for resources, that is, they are not endowed with a budget b of resources but instead have to pay for each unit of resources they acquire. We assume that the set of firms I competing for these resources is large enough such that each firm bids competitively for the same supply of resources.[2] In that case, the equilibrium price of resources, which we denote by w^*, is determined by the marginal benefit of investing more resources in either type of activities:

$$w^* \equiv \phi_y \cdot y'(b - x^*) \cdot [1 - \phi_a \cdot a(x^*)] = \phi_y \cdot y(b - x^*) \cdot \phi_a \cdot a'(x^*). \tag{8}$$

We can compare the equilibrium price of resources to what it would be in a benchmark economy that does not admit rent-seeking activities: $\phi_y \cdot y'(b)$. We refer to this quantity as the "marginal social value of resources", since it captures an alternative benchmark in which all resources are allocated "efficiently" to increase surplus, that is, without any diversion of resources to appropriate economic surplus already created. This benchmark also captures the standard practice in growth models of abstracting from rent-seeking activities.

If we focus our attention on how the resources allocated to surplus appropriation affect the marginal benefit of investing in surplus creation, we observe two forces going in opposite direc-

[2] If the number of firms competing for the same resources was small, the equilibrium price of resources could be inflated by what Glode and Lowery (2016) call a "defense premium": firm i would be willing to pay a premium to outbid firm j and prevent it from acquiring resources that could be used to steal firm i's surplus. We shut down this strategic bidding behavior from our model since it is superfluous to our paper's key insights.

tions. First, the fact that a fraction $[1-\phi_a \cdot a(x^*)]$ of the surplus a firm creates is appropriated by a rival firm lowers the marginal value of allocating resources for surplus-creating activities in the first place. Second, the fact that a firm finds it optimal to allocate resources to surplus appropriation reduces the quantity of resources allocated to surplus creation and increases the marginal benefit of performing the latter type of activities, $\phi_y \cdot y'(b-x^*)$, when $y(\cdot)$ is strictly concave. Overall, the existence of rent-seeking opportunities leads resources to be "overpriced" in a symmetric equilibrium whenever:

$$y'(b-x^*) \cdot [1-\phi_a \cdot a(x^*)] > y'(b). \tag{9}$$

This condition is most likely to be satisfied when $y(\cdot)$ is highly concave and the level of surplus appropriation remains low in equilibrium.

3.3 Firm output

We now analyze how industry-wide technological progress affects firm output. While most technological advancements should improve the productivity of surplus-creating activities, our analysis highlights that the benefits are mitigated by firms' overinvestment of resources in surplus-appropriating activities.

Consider a technological progress that improves the productivity of each type of activities by $d\phi_y > 0$ and $d\phi_a > 0$, respectively. Then, equilibrium firm output, as measured by $\phi_y \cdot y(b-x^*)$, will increase by:

$$y(b-x^*) \cdot d\phi_y - \phi_y \cdot y'(b-x^*) \cdot \frac{\partial x^*}{\partial \phi_a} \cdot d\phi_a. \tag{10}$$

The first term in this expression captures the increase in surplus creation for a given equilibrium allocation of resources whereas the second term captures the impact of the re-allocation of resources in response to $d\phi_a$ (remember that $d\phi_y$ does not affect the resource allocation decision). The resulting increase in firm output is inferior to what it would be under the benchmark allocation without rent seeking, that is, if all resources were allocated to surplus creation: $y(b) \cdot d\phi_y$. The wedge between benchmark and equilibrium output levels is affected by the current productivity parameters ϕ_y and ϕ_a in a non-linear way (recall the expression for $\frac{\partial x^*}{\partial \phi_a}$ derived in equation (7)). In what follows we parameterize the model to provide a numerical illustration in which the allocation of resources towards rent-seeking activities become so relevant that the relationship between productivity measures and equilibrium output appears to be concave, and even negative, in some parametric regions.

3.4 Parameterized example

To illustrate the intuition behind our insights, we parameterize the model by setting $a(x) = \frac{x}{1+x}$ and $y(s) = \frac{s}{1+s}$. The first-order condition that characterizes the optimal allocation of resources in a symmetric equilibrium then becomes:

$$\frac{1}{(1+b-x^*)^2} \cdot \left[1 - \phi_a \cdot \frac{x^*}{1+x^*}\right] = \frac{b-x^*}{1+b-x^*} \cdot \phi_a \cdot \frac{1}{(1+x^*)^2}, \tag{11}$$

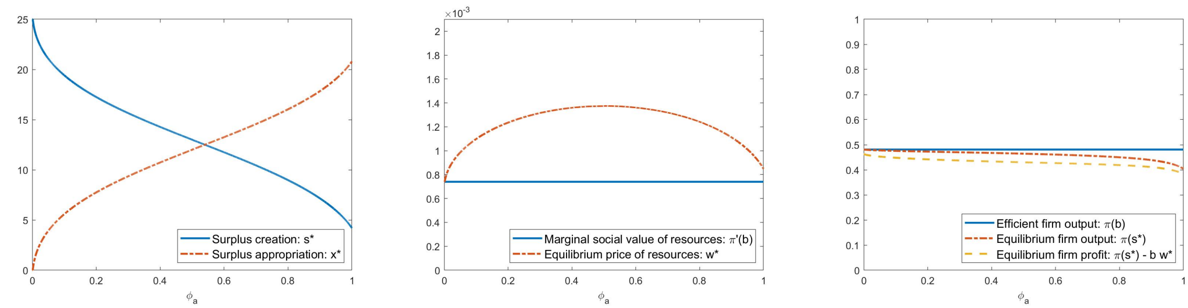
which pins down x^* as a function of the abundance of resources b and the productivity of surplus-appropriating activities, ϕ_a, independently of the productivity of surplus-creating activities, ϕ_y. The equilibrium price of resources is:

$$w^* = \phi_y \cdot \frac{1}{(1+b-x^*)^2} \cdot \left[1 - \phi_a \cdot \frac{x^*}{1+x^*}\right] = \phi_y \cdot \frac{b-x^*}{1+b-x^*} \cdot \phi_a \cdot \frac{1}{(1+x^*)^2}, \tag{12}$$

which does depend on the productivity of surplus-creating activities, ϕ_y.

To illustrate the impact of technological progress on the industry, we start with a simple scenario where technological progress is assumed to only improve the productivity of surplus-appropriating activities. This simple scenario will help highlight the perverse effect of excessively allocating resources to rent seeking in response to industry-wide technological progress. Then, we will generalize our analysis by allowing technological progress to affect both surplus-creating and surplus-appropriating activities.

Figure 2 plots, for various levels of ϕ_a, the optimal allocation of resources, the resulting price of resources, firm output and profit when each firm gains access to a supply $b = 25$ of resources and the productivity of surplus-creating activities is fixed at $\phi_y = 0.5$.



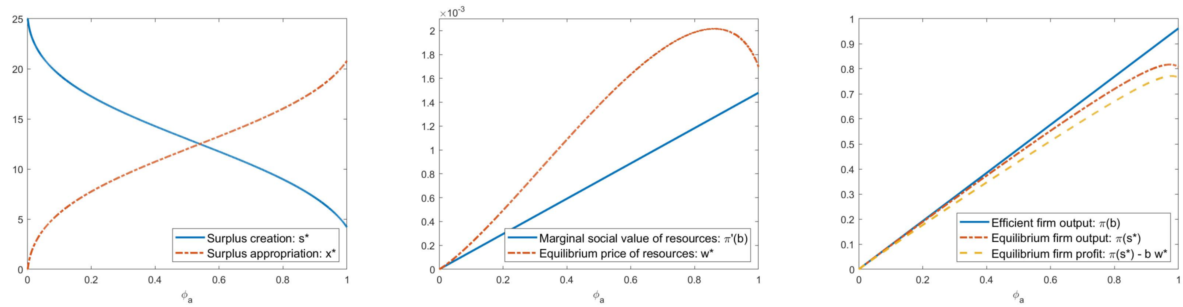
(a) Allocation of resources **(b)** Price of resources **(c)** Firm output/profit

Figure 2

Impact of technological progress in surplus-appropriating activities only. The graphs illustrate how varying the productivity of surplus-appropriating activities (i.e., ϕ_a), while keeping the productivity of surplus-creating activities constant (i.e., $\phi_y = 0.5$), affects the optimal allocation of resources, the resulting price of resources, firm output and profit when each firm gains access to a supply $b = 25$ of resources.

We can see from Panel (a) of Figure 2 that when $\phi_a = 0$ surplus appropriation is effectively shut down. As in our alternative benchmark without rent seeking, all resources are invested in surplus creation (i.e., $x^* = 0$ whereas $s^* = b$). However, as we increase ϕ_a, firms find it optimal to allocate more resources to surplus-appropriating activities. Due to the concavity of the production functions $y(\cdot)$ and $a(\cdot)$, the split of resources between surplus creation and appropriation inflates the price that firms are willing to pay for resources (i.e., w^*) above the marginal social value of these resources (i.e., $\pi'(b)$), as shown in Panel (b). Yet, once ϕ_a gets sufficiently large, firms invest so much resources in surplus appropriation that it lowers how much firms value resources in equilibrium. This explains the inverted-U shape of the price function, which is maximized when the economy displays an intermediate mix of resources used to create as well as appropriate surplus. Panel (c) shows that this allocation of resources leads firm output $\pi(s^*)$ to decrease and get further away from the benchmark level of output $\pi(b)$ as we increase ϕ_a. Once we account for the high cost of acquiring these resources in equilibrium, we see that firm profit can also decrease with industry-wide technological progress that solely improves the productivity of surplus-appropriating activities.

We now explore a richer and arguably more interesting scenario in which technological progress is assumed to improve the productivity of both types of activities: surplus creation and appropriation. In particular, Figure 3 plots the equilibrium allocation of resources, the resulting price of resources, firm output and profit when the productivity levels of surplus creation and surplus appropriation move in parallel, i.e., $\phi_y = \phi_a$, and each firm gains access to a supply $b = 25$ of resources.



(a) Allocation of resources **(b)** Price of resources **(c)** Firm output/profit

Figure 3
Impact of equal technological progress in both types of activities. The graphs illustrate how varying the productivity levels of surplus-appropriating activities and surplus-creating activities in parallel (i.e., $\phi_y = \phi_a$) affects the optimal allocation of resources, the resulting price of resources, firm output and profit when each firm gains access to a supply $b = 25$ of resources.

Even though ϕ_y and ϕ_a are now assumed to move together and affect to the same extent both the creation and appropriation of surplus, Panel (a) shows that firms still find it optimal to allocate more of their resources to surplus appropriation in response to industry-wide technological progress. In fact, Panel (a) of Figure 3 is identical to Panel (a) of Figure 2. As was clear from equation (4), any industry-wide technological progress in surplus creation boosts the rewards to surplus creation for a given firm in the same proportion that it boosts the rewards from appropriating its rival's (now larger) surplus. Thus, the level of ϕ_y does not enter a firm's optimal allocation decision and any industry-wide technological progress to both types of activities directly results in more overinvestment in surplus appropriation. While the marginal social value of resources is increasing with ϕ_y, we see from Panel (b) that the equilibrium price of resources is still inflated to a higher level by the inefficient investment of resources in surplus-appropriating activities. Moreover, despite the fact that our parameterization features production functions $\pi(\cdot)$ and $\alpha(\cdot)$ that are linear in the productivity parameters $\phi_y = \phi_a$, we can see from Panel (c) of Figure 3 that equilibrium output is concave in these productivity measures (unlike the socially efficient output). This concavity is driven by firms' response to technological progress that increases the productivity of both types of activities. Firms respond to this progress by allocating a smaller share of their resources to surplus creation.

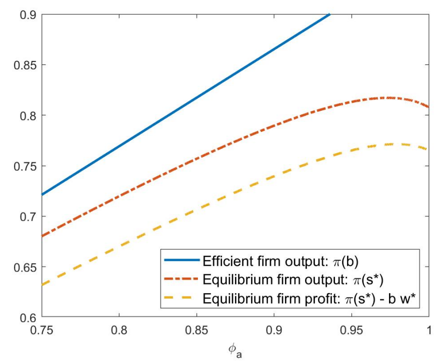
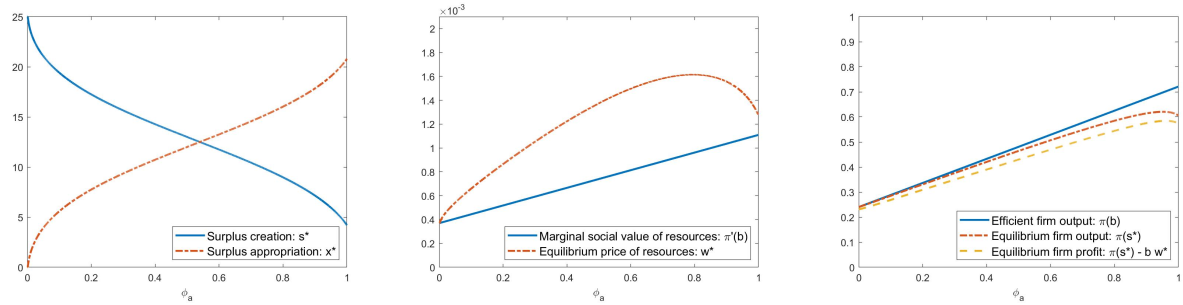


Figure 4
Non-monotonic relationship between firm output/profit and technological progress in both types of activities. The graph illustrates how varying the productivity levels of surplus-appropriating activities and surplus-creating activities in parallel (i.e., $\phi_y = \phi_a$) affects firm output and profit for high productivity levels when each firm gains access to a supply $b = 25$ of resources.

We even see in Figure 4, which zooms in on the region where $\phi_a \in [0.75, 1]$, that further technological progress can result in a drop in firm output and profit when the productivity parameter becomes large enough. Thus, the negative impact of firms' misallocation of resources on output and profit can be so severe that it dominates the positive impact of higher productivity due to industry-wide technological progress.

Finally, we consider for the sake of robustness a scenario that can be interpreted as a mixture of the previous parameterizations: we set $\phi_y = 0.5 + 0.5 \cdot \phi_a$. Figure 5 shows patterns in allocation, price, firm output and profit that are all consistent with the takeaways from Figures 2, 3, and 4.



(a) Allocation of resources

(b) Price of resources

(c) Firm output/profit

Figure 5

Impact of unequal technological progress in both types of activities. The graphs illustrate how varying the productivity levels of surplus-appropriating activities and surplus-creating activities at different rates (i.e., $\phi_y = 0.5 + 0.5 \cdot \phi_a$) affects the optimal allocation of resources, the resulting price of resources, firm output and profit when each firm gains access to a supply $b = 25$ of resources.

4 Extensions

In this section, we show how our main theoretical insights extend in a variety of alternative environments.

4.1 Multiple rival firms

For tractability, our baseline analysis assumed that each firm i was appropriating the surplus of one rival firm (i.e., firm j) and vice-versa. However, all our insights survive in an environment where firms have several rivals competing for their surplus. If firm i has N rivals, we can write its payoff as:

$$\pi_i(s_i) \cdot \left[1 - \sum_{j=1}^{N} \alpha_j(x_j)\right] + \sum_{j=1}^{N} \pi_j(s_j) \cdot \alpha_i(x_i). \tag{13}$$

With industry-wide technological parameters, firm i's first-order condition becomes:

$$y'(s_i) \cdot \left[1 - \phi_a \cdot \sum_{j=1}^{N} a(x_j)\right] = \sum_{j=1}^{N} y(s_j) \cdot \phi_a \cdot a'(x_i). \tag{14}$$

A firm's optimal allocation of resources behaves similarly, from a qualitative standpoint, when $N > 1$ as it does in our baseline model (where $N = 1$). In particular, the productivity of surplus creation ϕ_y does not enter the first-order condition, which implies that technological progress tilts the allocation of resources towards rent seeking whenever such progress increases ϕ_a.

4.2 Relative investment in surplus appropriation

In our baseline analysis, we assumed that firm i could invest resources to appropriate firm j's surplus whereas firm j could invest resources to appropriate firm i's surplus. In some contexts, however, firm i's investments in surplus-appropriating activities are also associated with the added benefit of reducing rival firms' ability to appropriate firm i's surplus. For example, a technology firm can build a legal department aimed at finding loopholes in rival firms' patents *and* protecting the firm's own patents from infringement by rival firms (evidence of these practices has been recently provided by Argente et al. 2020). In such instances, firm i's ability to appropriate firm j's surplus could be modeled as a function of firm i's investment in surplus-appropriating activities relative to that of firm j. Formally, using notation similar to our baseline analysis we can denote each firm's payoff as:

$$\pi_i(s_i) \cdot [1 - \alpha_j(x_j - x_i)] + \pi_j(s_j) \cdot \alpha_i(x_i - x_j). \tag{15}$$

With industry-wide productivity parameters, the first-order condition becomes:

$$y'(s_i) \cdot [1 - \phi_a \cdot a(x_j - x_i)] = \phi_a[y(s_i) \cdot a'(x_j - x_i) + y(s_j) \cdot a'(x_i - x_j)]. \tag{16}$$

As in the baseline model, the productivity of surplus-creating activities drops out of the first-order condition. Moreover, in a symmetric equilibrium, the first-order condition can be written as:

$$y'(b - x^*) \cdot [1 - \phi_a \cdot a(0)] - 2\phi_a \cdot y(b - x^*) \cdot a'(0) = 0. \tag{17}$$

By applying the implicit function theorem, we get:

$$\frac{\partial x^*}{\partial \phi_a} = \frac{y'(b-x^*)\cdot a(0) + 2y(b-x^*)\cdot a'(0)}{-y''(b-x^*)\cdot[1-\phi_a\cdot a(0)] + 2\phi_a\cdot y'(b-x^*)\cdot a'(0)} > 0. \tag{18}$$

As in the baseline model, a technological progress that increases ϕ_a leads firms to tilt their allocation of resources towards surplus appropriation (regardless of what happens to ϕ_y). As a result, the main insights we derive in the baseline analysis survive when the *relative* investment in rent seeking is what drives the fraction of its rival's surplus a firm can appropriate (i.e., $\alpha(\cdot)$).

4.3 Factor-augmenting technological changes

In our baseline analysis, we have focused on a technological change improving total factor productivity (TFP), as surplus-creating and surplus-appropriating activities display production functions of the form $\phi_y \cdot y(s)$ and $\phi_a \cdot a(x)$, respectively. In such environment, we have shown that the allocation of resources between the two types of activities only depends on ϕ_a. In this extension, we show that this result also holds when considering factor-augmenting technological changes within the family of standard Cobb-Douglas production functions.

To see this equivalence, the "Cobb-Douglas version" of the TFP-augmenting technological change analyzed in the baseline model yields the following specifications: $\pi(s) = \phi_y \cdot y(s) = \phi_y \cdot s^\eta$ for surplus-creating activities and $\alpha(x) = \phi_a \cdot a(x) = \phi_a \cdot x^\gamma$ for surplus-appropriating activities. Then, with a budget constraint that is binding (i.e., $s = b - x$), we get the following expressions:

$$\pi'(b-x) = \phi_y \cdot y'(s) = \eta\frac{\pi(b-x)}{b-x} \qquad \text{and} \qquad \alpha'(x) = \phi_a \cdot a'(x) = \gamma\frac{\alpha(x)}{x}. \tag{19}$$

The first-order condition in a symmetric equilibrium can then be rewritten as:

$$\eta\frac{\pi(b-x^*)}{b-x^*}[1-\alpha(x^*)] = \pi(b-x^*)\gamma\frac{\alpha(x^*)}{x^*} \qquad \Longrightarrow \qquad \frac{\alpha(x^*)}{1-\alpha(x^*)} = \frac{\eta x^*}{\gamma(b-x^*)}, \tag{20}$$

which replicates, for the case of Cobb-Douglas production functions, our previous result that the allocation of resources only depends on the productivity level of surplus-appropriating activities.

Now, consider an alternative specification that allows for factor-augmenting technological changes: $\pi(s) = y(\phi_y \cdot s) = (\phi_y \cdot s)^\eta$ for surplus-creating activities and $\alpha(x) = a(\phi_a \cdot x) = (\phi_a \cdot x)^\gamma$ for surplus-appropriating activities. In this case, the technological change does not increase the whole production, but it operates through a direct increase of the factor of production. Yet, taking derivatives with respect to the resources invested yields the same expressions as in (19), and as a result the first-order condition is also given by (20). Our model's main results thus hold whether we model technological progress as factor augmenting or as TFP augmenting.

5 Applications

In this section, we explore how our theoretical framework could apply for several types of surplus-appropriating activities: (i) civil litigation, (ii) product imitation, (iii) speculative trading, and (iv) government lobbying.

5.1 Civil litigation

While advances in telecommunications, data gathering, and social media may have helped firms create more social surplus, they may also have made it easier for rent-seeking parties to collect evidence, put social pressure, and coordinate with other potential claimants with hopes of extracting surplus from rival firms through means of civil litigation. Consequently, our model's insights might help to shed light on the extraordinary growth of the law profession over the last few decades (see Figure 6).

We now show how our baseline analysis can be applied to capture firms' decision to allocate resources between production and civil litigation. Suppose that when firm j operates, it provides to rival firm i a probable cause to file a (socially wasteful) lawsuit with probability λ. In line

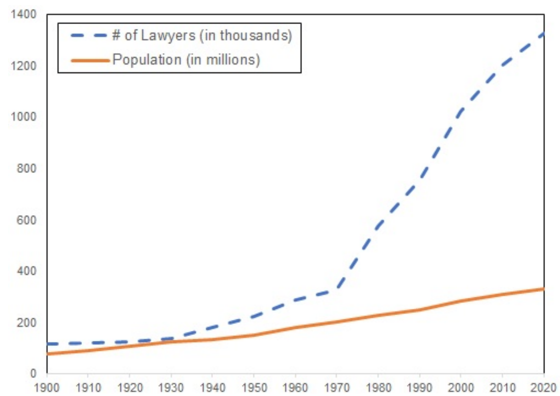


Figure 6
Growth of law profession. The figure plots the number of lawyers in the US (in thousands) and the overall US population (in millions) between 1900 and 2020. Data Sources: American Bar Association's 2020 Profile of the Legal Profession and 2020 US Census.

with Guerra, Luppi, and Parisi (2018) and the reference therein, we assume that the quantity of resources x_i a plaintiff i invests in litigation (e.g., gathering evidence and hiring the best lawyers for the case) increases the probability $\rho_i(x_i)$ that the plaintiff prevails (whether it is in or out of court) and becomes entitled to a compensation κ from the defendant j.[3] Yet, defendant j's ability to pay what it owes to the plaintiff in this case depends on the profits $\pi_j(s_j)$ it generates with its core business, where s_j denotes the resources invested in the core business. Specifically, given the limited liability status of corporations, the payoff firm i collects from winning a lawsuit against firm j is given by $min\{\kappa, \pi_j(s_j)\}$.

Since firm i is a threat to sue firm j and firm j is a threat to sue firm i, the expected payoff for firm i is given by:

$$\pi_i(s_i) - \lambda\rho_j(x_j) \cdot min\{\kappa, \pi_i(s_i)\} + \lambda\rho_i(x_i) \cdot min\{\kappa, \pi_j(s_j)\}. \qquad (21)$$

[3]Recall that in Section 4 we extended our analysis to allow a firm's investment in surplus-appropriating activities to lessen its rival firms' ability to appropriate this firm's surplus. If we imposed this assumption in the current context of civil litigation, it would be akin to allowing a firm to use its legal experts to defend itself better against rivals' lawsuits in addition to suing them with more success.

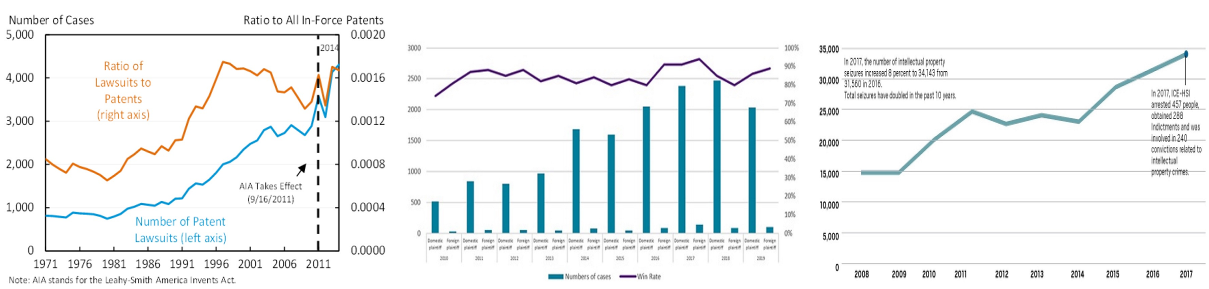
When κ is large enough and firms' limited liability binds, this expression simplifies to:

$$\pi_i(s_i) \cdot [1 - \lambda\rho_j(x_j)] + \pi_j(s_j) \cdot \lambda\rho_i(x_i), \tag{22}$$

and we are back to the profit expression (1) that we started with, where $\alpha_i(x_i) = \lambda\rho_i(x_i)$. As in our baseline analysis, a firm's operating profit $\pi_i(s_i)$ contributes to the total surplus, but its civil litigation payoff $\lambda\rho_i(x_i) \cdot \pi_j(s_j)$ is solely a transfer from firm j. Thus, industry-wide technological progress that boosts the marginal productivity of civil litigation (i.e., $\lambda\rho_i'(x_i)$) will result in a reallocation of resources toward this rent-seeking activity, even when the marginal productivity of the firms' core business also increases.

5.2 Product imitation

As pointed out in the introduction, an obvious example of surplus-appropriating activities is product imitation. Improvements in production speed, 3D printing, and telecommunications might have led firms to spend more resources on reverse engineering and corporate espionage with hopes of appropriating rents from innovative firms. Our model's insights can thus shed light on the recent growth in patent infringement and product counterfeiting (see Figure 7).



(a) Patent infringement cases in US **(b)** Patent infringement cases in UK **(c)** Seizures of counterfeit products in US

Figure 7
Growth in imitation. Panel (a) plots the growth in the number of patent infringement cases in the US (adapted from Council of Economic Advisers 2016). Panel (b) plots the growth in the number of patent infringement cases in the United Kingdom (UK) (adapted from Zhang and Qiao 2020). Panel (c) plots the growth in the number of products seized by the US Government due to trademark and copyright violations (adapted from Snibbe 2019).

Applying our model to the context of product imitation resembles what we did for the civil litigation setting, thus we use similar notation and keep the description brief. Assume a firm j that can either spend resources s_i on researching and developing new technologies, which increases the surplus $\pi_j(s_i)$, or can spend resources x_i on reverse engineer the developments from rival firm i, which yields a successful imitation of firm i's technology with probability $\rho_i(x_i)$. When imitation is successful, firm j captures a fraction λ of firm i's market (and surplus). If firm i also makes the same allocation decision, its expected payoff is:

$$\pi_i(s_i) + \lambda\rho_i(x_i)\pi_j(s_j) - \lambda\rho_j(x_j)\pi_i(s_i), \tag{23}$$

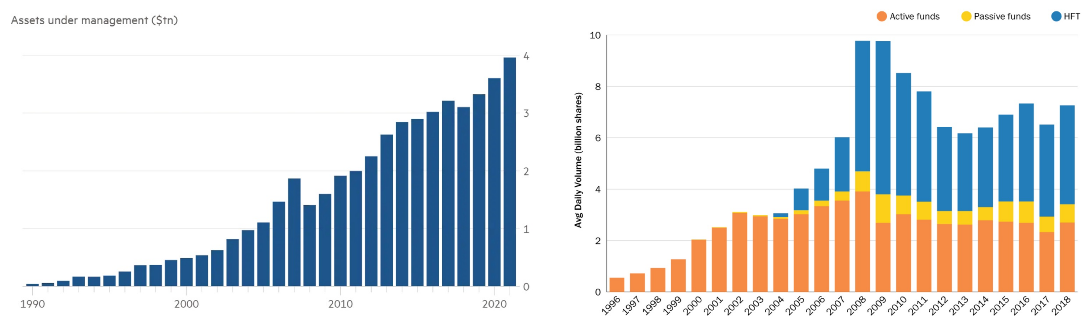
which simplifies to:

$$\pi_i(s_i) \cdot \left[1 - \lambda\rho_j(x_j)\right] + \pi_j(s_j) \cdot \lambda\rho_i(x_i). \tag{24}$$

Again, we recover the original profit expression (1), where $\alpha_i(x_i) = \lambda\rho_i(x_i)$. As in our baseline analysis, a firm's innovation profit $\pi_i(s_i)$ contributes to the total surplus, but its imitation payoff $\lambda\rho_i(x_i) \cdot \pi_j(s_j)$ is solely a transfer from firm j (and vice-versa for firm j's imitation payoff). Thus, industry-wide technological progress that boosts the marginal productivity of activities such as espionage, reverse-engineering, and imitation (i.e., $\lambda\rho_i'(x_i)$) will result in a reallocation of resources toward these rent-seeking activities, even when the marginal productivity of the firms' innovations also increases.

5.3 Speculative trading

This application builds on the model of Glode and Lowery (2016) and highlights how advancements in financial modeling, data collection, and telecommunications might have contributed to a disproportionate re-allocation of resources within the financial sector towards surplus-appropriating activities such as speculative trading. In particular, our model's insights can shed light on how technological progress might have contributed to the rising popularity of hedge funds and high-frequency trading in recent years (see Figure 8). They can also shed light on the rise in the relative wage earned by financial-sector workers and the fact that the re-allocation of resources and the increased compensation were not associated with an increased efficiency in financial intermediation (see Figure 9).



(a) Worldwide hedge fund AUM

(b) US trading volume

Figure 8

Growth in speculative trading. Panel (a) plots the growth in assets under management (AUM) at hedge funds worldwide (adapted from Wigglesworth and Fletcher 2021). Panel (b) plots the growth and composition of average daily trading volume in the US (adapted from Klein 2020).

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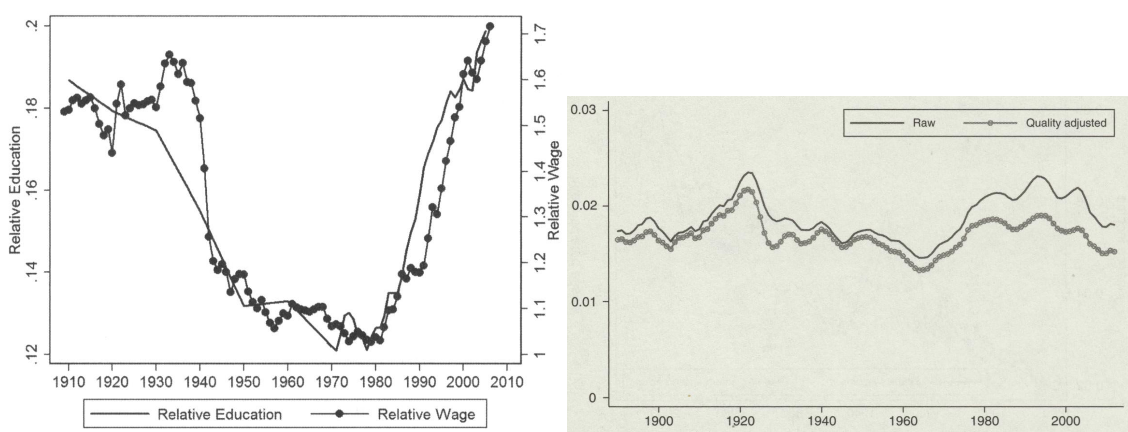


(a) Relative wage of US finance workers

(b) Unit cost of financial intermediation

Figure 9

Financial-sector compensation and efficiency. Panel (a) plots the relative wage of US financial-sector workers (see Philippon and Reshef 2012). Panel (b) plots the unit cost of financial intermediation in the US (see Philippon 2015).

Specifically, consider financial firms searching for profitable investment opportunities such as entrepreneurs with great ideas and credit-worthy businesses that need loans to expand their operations. Each financial firm j can invest resources s_j to increase the probability $\mu_j(s_j)$ of finding such investment with an expected future payoff of $\bar{v}$. Conditional on making such investment, firm j is hit with probability ξ by a liquidity shock that drives the firm's valuation of its investment to zero. If that is the case, the firm contacts a counterparty i, which was not hit by a similar liquidity shock, and tries to sell a security backed by the (illiquid) investment. We assume that the firm selling its investment quotes a take-it-or-leave-it offer price p to its counterparty.

In preparation for this possibility, each counterparty can allocate some of its resources to acquire expertise (e.g., data, computers, human capital) that will help it value the security it might be offered by a selling firm. Specifically, we assume that a firm i can receive with probability $\theta_i(x_i)$ a private signal disclosing whether the security backed by firm j's investment is worth $2\bar{v}$ or zero (two equally likely outcomes). Thus, a firm hit by a liquidity shock can quote to its counterparty a price $p = \bar{v}$ for the security, which is accepted whenever the buyer does not receive a private signal that the security is worth zero, or it can quote a price $p = 2\bar{v}$ for the security, which is only accepted when the buyer receives a private signal that the security is worth $2\bar{v}$. Without knowing whether its counterparty i has received a private signal or not, firm j finds it optimal to quote a price $p = \bar{v}$ rather than $p = 2\bar{v}$ as long as $\left(1 - \frac{\theta_i(x_i)}{2}\right)\bar{v} \geq \frac{\theta_i(x_i)}{2} 2\bar{v}$, which simplifies to $\theta_i(x_i) \leq \frac{2}{3}$. If this condition is satisfied, firm i makes a trading profit of $(2\bar{v} - \bar{v})$ whenever it receives a private signal that the security is worth $2\bar{v}$ and pays $p = \bar{v}$ for it. Considering that firm i is firm j's counterparty and vice-versa, the expected payoff for a given firm i, before knowing its role as a buyer or seller, is then:

$$(1-\xi)\mu_i(s_i)\bar{v} + \xi\mu_i(s_i)\left(1 - \frac{\theta_j(x_j)}{2}\right)\bar{v} + \xi\mu_j(s_j)\frac{\theta_i(x_i)}{2}(2\bar{v} - \bar{v}), \tag{25}$$

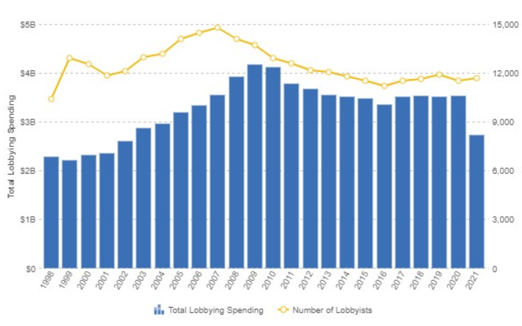
which simplifies to:

$$\mu_i(s_i)\bar{v} \cdot \left[1 - \frac{\xi\theta_j(x_j)}{2}\right] + \mu_j(s_j)\bar{v} \cdot \frac{\xi\theta_i(x_i)}{2}. \tag{26}$$

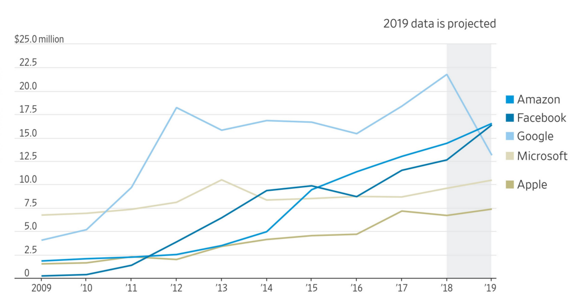
We are then back to the profit expression (1) that we started with, where $\pi_i(s_i) = \mu_i(s_i)\bar{v}$ and $\alpha_i(x_i) = \frac{\xi \theta_i(x_i)}{2}$. As in our baseline analysis, a firm's investment payoff $\mu_i(s_i)\bar{v}$ contributes to the total surplus, but its profit from informed trading $\mu_j(s_j)\bar{v} \cdot \frac{\xi \theta_i(x_i)}{2}$ is solely a transfer from firm j. Thus, industry-wide technological progress that boosts the marginal productivity of informed trading (i.e., $\frac{\xi \theta_i'(x_i)}{2}$) will result in a reallocation of resources toward this rent-seeking activity, even when the marginal productivity of the firms' core business also increases. As a consequence of this reallocation, the sector's overall productivity will not feature a boost consistent with the technological progress, yet the price paid for the resources invested in all financial activities will increase.

5.4 Government lobbying

Innovations in telecommunication and transportation technologies have facilitated government lobbying, which consists of investing resources in convincing regulators and politicians to make decisions that favor an organization. Indeed, recent decades have featured impressive growth in the resources spent on government lobbying, especially coming from the technology sector (see Figure 10).



(a) US total lobbying spending (inflation-adjusted)



(b) Lobbying spending by large US tech firms

Figure 10

Growth in government lobbying. Panel (a) plots the growth in inflation-adjusted lobbying spending targeting US Congress and federal agencies (adapted from OpenSecrets 2021). Panel (b) plots the growth in lobbying spending by large US technology firms (adapted from Tracy 2019).

We now show our analysis can be adapted to capture firms' decision to spend on government lobbying. Suppose the government taxes the taxable income of two firms in an industry, firms i and j, at a fixed rate τ. This money is then redistributed among these two firms through transfers like subsidies and grants, based on various governmental objectives. However, by investing resources on lobbying efforts, a firm can convince government officials to increase at a rate β the fraction of the total taxes collected that returns to this firm. Specifically, without lobbying, each firm is expected to collect half of the total taxes collected, that is, $\frac{1}{2}\tau[\pi_i(s_i)+\pi_j(s_j)]$, where $\pi_i(s_i)$ is the taxable income of firm i (similar notation for firm j). But with lobbying spending of x_i and x_j by the two firms, firm i expects to receive a subsidy of:

$$\left(\frac{1}{2}+\beta x_i-\beta x_j\right)\tau[\pi_i(s_i)+\pi_j(s_j)]. \tag{27}$$

Thus, the payoff firm i expects to collect when investing s_i in increasing the taxable income coming from its core business and investing x_i in lobbying activities is:

$$(1-\tau)\pi_i(s_i)+\left(\frac{1}{2}+\beta x_i-\beta x_j\right)\tau[\pi_i(s_i)+\pi_j(s_j)], \tag{28}$$

which simplifies to:

$$\pi_i(s_i)\cdot\left[1-\tau\left(\frac{1}{2}+\beta(x_j-x_i)\right)\right]+\pi_j(s_j)\cdot\tau\left(\frac{1}{2}+\beta(x_i-x_j)\right). \tag{29}$$

We are then back to the profit expression (15) that we derived in the extension of Section 4 that features relative investments in surplus appropriation, where $\alpha_i(x_i-x_j)=\tau\left(\frac{1}{2}+\beta(x_i-x_j)\right)$. As in our baseline analysis, a firm's investment payoff $\pi_i(s_i)$ contributes to the total surplus, but the additional transfer associated with lobbying $\pi_j(s_j)\cdot\tau\beta(x_i-x_j)$ is solely a transfer from firm j. Thus, industry-wide technological progress that boosts the marginal productivity of government lobbying (i.e., β) will result in a reallocation of resources toward this rent-seeking activity, even when the marginal productivity of the firms' core business also increases.

6 Conclusion

We show that when technology is used to facilitate surplus-creating as well surplus-appropriating activities, albeit to different extents, industry-wide technological advancements such as big data, machine learning, and artificial intelligence create a disproportionate reallocation of resources towards surplus-appropriating activities. Over time, the economy evolves towards a rent-seeking economy in response to this technological progress. Moreover, the long-run reallocation of resources towards surplus appropriation has important implications for the relative price of resources that can serve as inputs for all types of activities as well as for the benefits of technological breakthroughs on economic growth.

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