Creative Destruction, Finance, and Firm Dynamics

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Abstract

New ideas are the engine of sustained economic growth and creative destruction. However, the processes through which they are generated and embedded in economic activity are laden with numerous inefficiencies. This paper provides an overview of the research on these processes and the associated bottlenecks, with an emphasis on the effects of finance and firm dynamics on the discovery, reallocation, and implementation of new ideas. A new endogenous growth model with collateral constraints is developed to highlight the interaction of financial frictions with firm innovation.

Keywords: creative destruction, economic growth, finance, financial frictions, firm dynamics, industry dynamics, innovation, inventors, mergers and acquisitions

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1 Introduction

New ideas are the engine of sustained economic growth, and the creative destruction that ensues in their wake is among the primary drivers of firm and industry dynamics. Sometimes, these new ideas manifest as small yet continuous improvements in how we combine inputs into outputs in a more efficient manner. At other times, innovations can disrupt entire industries, or better yet, lead to the generation of completely new ones. At the firm level, a new invention can help a firm outshine its competitors; and at the country level, technology is what separates developed countries from developing ones, with all the implications it carries for living standards. Given these observations, it is not possible to overemphasize the importance of new ideas for social welfare and progress.

The processes through which these new ideas are generated and embedded in economic activity, however, are by no means simple or free of problems. From the very possibility of an idea's generation to its eventual use in production, there are several steps the idea must go through, each laden with various inefficiencies. Identifying and alleviating these inefficiencies has been a significant research area for economists since the seminal contribution of Philippe Aghion and Peter Howitt (Aghion and Howitt (1992)), and one of the pillars of endogenous growth theory. In this paper, I will seek to provide a broad overview of these various inefficiencies and highlight areas that require more scrutiny in future research, with a particular emphasis on how finance and firm dynamics affect the discovery of new ideas, and the creative destruction they cause.

To tally the major steps of the generation of economic growth through new ideas, it helps to imagine a hypothetical idea, and contemplate its lifecycle and the associated problems:

- Ideas come into existence only as a result of the mental effort of those who conceive them. However, those with the ability, training, and resources to come up with new ideas are scarce. Can financial frictions and other distortions faced by individuals affect the size and the quality of the pool of innovators?

- The generation of an idea is insufficient for it to affect economic growth. It must be incarnated in a service or product, or enhance a process. This can require considerable investment and funding, which the owner of an idea might not possess due to financial frictions. Can financial frictions faced by firms affect the efficiency and speed at which ideas are integrated into production?

- Ideas may not always occur to, or be owned by, their best users. Sometimes, the owners might not have the funds or the infrastructure to commercialize the ideas. At other times, the technological fit between ideas and their owners might be too low, due to the serendipitous nature of innovation. Some firms might also want to acquire innovations developed by other firms, instead of relying on in-house research and development (R&D). A market for ideas exists to resolve the inefficiencies in the ownership of ideas, where they can be reallocated through licensing agreements, patent sales, or wholesale acquisition of a firm by another. What are the inefficiencies inherent in these markets, and how important are they?

In the remainder of this paper, I will focus on each step in this extensive, yet inevitably incomplete, list. Section 2 scrutinizes the role of financial frictions on the selection of inventors. Section 3 focuses on the impact of financial frictions faced by firms on their discovery and commercialization of new ideas, and presents a new endogenous growth model with collateral constraints. Section 4 considers the various inefficiencies in the market for ideas and mergers and acquisitions (M&A) between innovative firms. Section 5 concludes.

2 The Selection of Inventors and Financial Frictions

Every idea has an innovator. However, not every person has the chance to become one. Inventors of patents, scientists that produce breakthrough research, and entrepreneurs that implement new business ideas constitute a small and selected population. This selection is influenced to a great degree by financial considerations, be it the availability of parental resources, funds to acquire necessary training, or the capital needed to finance new prototypes or start-ups. These bottlenecks can influence both the quality and quantity of ideas a society can come up with.

Allocation of talent – assigning the right people to the right jobs – can have a first-order effect on the productivity of a society. The susceptibility of the allocation mechanism to be distorted away from the socially optimal outcome by private expenditures might create significant welfare losses in the presence of high levels of inequality in private resources. The losses are especially magnified if the best and the brightest of a society are not allocated to the professions where their social contribution would be the greatest. Scientists and inventors, as producers of new knowledge and inventions, are certainly among the professions where this effect might be the greatest, since they produce public goods that everyone can benefit from.

Consider the example of Albert Einstein. As a scientist and inventor, he produced over 300 scientific papers and 50 patented inventions. His groundbreaking contributions in the field of physics have birthed a paradigm shift, and led to the discovery of countless new ideas and inventions. However, he did not become such a prolific innovator in a vacuum. His father, Hermann Einstein, was a rich salesman and engineer, and owned his own company that manufactured electrical equipment based on direct current. Thanks to his parental background, Albert Einstein was able to receive education in various high-quality schools in Germany, Italy, and Switzerland, including his alma mater, ETH Zurich. How would the world look like, if Einstein was not able to receive the necessary education to be a scientist and an inventor, and became a factory worker instead? Better yet, how do we know if we are not missing out on potential Einsteins right now?

Over the past decade, several papers have investigated who become inventors, and which inventors turn out to be the most prolific among those, using data from a variety of sources. Using inventor, patent, and census data from the United States, Celik (2016) finds that individuals from richer backgrounds are much more likely to become inventors, but this is not true for those from more educated backgrounds. At the same time, conditional on becoming an inventor, those from more educated backgrounds turn out to be much more prolific inventors measured using a wide array of inventor productivity metrics, whereas those from richer backgrounds exhibit no such aptitude. Interestingly, this high predictive power of family background is despite the use of surname-level information from two to three generations ago, implying that social mobility is quite low when it comes to what determines a person's likelihood to become an inventor. Using social security data from the US, Bell, Chetty, Jaravel, Petkova, and Van Reenen (2019) also find that individuals from higher income families are more likely to become inventors. Aghion, Akcigit, Hyytinen, and Toivanen (2018) use a richer dataset from Finland, where individuals are directly linked to their parents and, in the case of men, IQ test results. They also show that parental income has a significant predictive power for who becomes an inventor even when controlling for IQ test scores, but the positive correlation becomes economically insignificant once the education of the individual (i.e., having a PhD) is controlled for. Akcigit, Grigsby, and Nicholas (2017) report the same holds even during the "golden age of innovation" in the US in the 1940s, showing that these patterns are not a recent phenomenon specific to the more recent data on inventors (1976+).

The documented positive correlation between who becomes an inventor and the income of their family, by itself, is not a direct cause for concern. If the unobserved ability has any intergenerational persistence – be it through nature or nurture – the observed correlation pattern would emerge even if the allocation of talent in innovation was perfectly meritocratic, as the parents of talented individuals would have a higher probability to be talented themselves compared to the population mean. A problem arises, however, if observable characteristics that predict performance as an inventor do not coincide with those that predict selection into the pool of inventors, as documented in Celik (2016). In the United States, those from more educated backgrounds are found to be more prolific inventors by a considerable margin, but they are not the ones who have an advantage in becoming inventors. On the other hand, some individuals do become inventors if they originate from richer families, yet turn out to be quite mediocre after they make it into the profession. These correlation patterns suggest that the rich might have an advantage in giving their children a leg up in the competition to become an inventor.

A closer look at the data suggests pathways through which higher parental resources can help guarantee a higher probability to become an inventor, irrespective of talent. NSF National Survey of College Graduates (2003) reveals that two thirds of the inventors in the US have a graduate degree, whereas half of those are PhDs. As seen in Aghion, Akcigit, Hyytinen, and Toivanen (2018), even in Finland which boasts a publicly-funded education system, higher parental resources predict a higher probability of receiving a PhD. In the United States, the competition for receiving a prestigious degree is much fiercer. Parents spend considerable time and resources to improve the likelihood that their children obtain the best credentials possible. The most direct way they can help is to pay the tuition and living expenses for prestigious colleges, which can go up to 3-4 times the net wage of the median worker. But much more extravagant options exist as well. In a 2018 lawsuit, New York-based private college counseling firm Ivy Coach was revealed to charge a client $1.5 million to help their child with college and boarding school applications. Other families are known to found charitable non-governmental organizations with their children installed as the manager in an effort to give a boost to the non-curricular activities part of their application. In such a high-stakes environment, it is difficult for talented individuals from poor families to compete on equal footing, who often have to brood over more ordinary problems such as whether they will be able to pay back their student loans after graduation even if they are admitted to their desired programs, or whether they should simply skip college and join the workforce instead.

To quantify the effects of the misallocation of talent in innovation due to differences in parental resources and to analyze potential policy changes that can alleviate the inefficiency, Celik (2016) develops an endogenous growth model with a rich household side in the vein of heterogeneous agents models such as Aiyagari (1994). The households are heterogeneous in wealth, education, and unobserved innate ability that is persistent across generations. Parents invest in the education of their offspring and leave bequests. The training necessary to become an inventor is scarce; hence individuals compete against each other in a tournament setting to receive it. Factors that improve inventor productivity such as innate ability and education increase the probability of receiving this training, but so does private credentialing spending which is unproductive by itself. Thus, individuals who inherit generous bequests can become inventors even if they are of mediocre talent through excessive spending on credentialing, preventing more talented individuals from poorer backgrounds from becoming one. This is individually rational but socially inefficient; reducing the quality of the inventor pool used in generating productivity-improving innovations that drive economic growth in the absence of intervention. The estimated model suggests that shutting down the unproductive credentialing spending channel would achieve a 21 basis points increase in long-run growth, and a 6% increase in consumption-equivalent welfare through allocating the most talented individuals to the professions where their contribution is the greatest.

Finding policies that can alleviate this misallocation of talent in a decentralized economy is tougher. While changes in college admission standards could in theory reduce the friction, it is unlikely to completely counteract the advantages conferred to individuals who originate from rich families over the "missing Einsteins" from underprivileged backgrounds. The mismatch between talent and wealth lies at the heart of the problem – if the talented and the wealthy coincided perfectly, a near-perfect allocation of talent would arise despite the unproductive spending on the credentialing rat-race. Motivated by this observation, Celik (2016) considers progressive taxation of bequests and inter-vivos transfers coupled with lump-sum transfers, and finds that this policy could achieve one quarter of the previously-mentioned gain in long-run growth at 5 basis points. Increasing the amount of scholarships available for tuition and living expenses for talented applicants could be another, more targeted, policy. Any potential policy, however, has to compete with alternative policies that could prove equally worthwhile in boosting innovation and economic growth. Akcigit, Pearce, and Prato (2020) study the optimal allocation of funds between R&D subsidies and public investment in higher education using Danish micro-data. They find that a combined policy works best, and that education policy would be more effective in societies with high income inequality, for which the United States would be an example.

3 Financing the Discovery and Development of Ideas

Coming up with an idea does not enhance productivity by itself. It must first be implemented and commercialized, and made a part of the system of production. It must be refined by follow-up research and development efforts so that the idea can manifest as a new product or service, or improve existing production processes. All of these can require a substantial amount of funds which might be hard to come by, especially so for small or young firms. As a result, financial frictions can potentially reduce or delay the incorporation of new ideas into the economy.

There exists an extensive literature that studies the effects of financial frictions on firm investment and dynamics, with prominent papers such as Kiyotaki and Moore (1997), Jeong and Townsend (2007), Buera (2009), Amaral and Quintin (2010), Buera, Kaboski, and Shin (2011), Buera and Shin (2013), Midrigan and Xu (2014), Moll (2014), and Cole, Greenwood, and Sanchez (2016). Despite the extensive literature, how financial frictions and innovation interacts has received comparatively less attention on the theory front compared to firms' investment in tangible assets, such as land, plants, machinery, vehicles, and so on. Financing innovation is quite different from that for tangible assets. Innovation is oftentimes a very risky process that can fail to generate any value, which would make any potential investor anxious to begin with. Even when successful, the resultant ideas can be patented, but patents are much harder to value and transfer than tangible assets, making them less effective as collateral to finance future investment. All these factors separate the financing of innovation from more tangible types of investment available to firms. In the rest of this section, I will develop a simple model to highlight these differences, and discuss their implications.

3.1 A Simple Model of Innovation Under Financial Frictions

3.1.1 Overview

Time is continuous and denoted by $t \geq 0$. At any point in time, there is a mass $M_t > 0$ of firms that own a mass $N_t > 0$ of product lines. Individual firms own a collection of product lines. Each product line allows a firm to use physical capital as an input to produce the final good. Production exhibits decreasing returns to scale. The final good is sold in a competitive market. Firms are subject to financial frictions. The amount of physical capital a firm can use depends on the equity of a firm, which is modeled as a collateral constraint. Firms can add new product lines to their portfolio through successful innovation. Firms increase their chance of success in innovation through R&D investment. R&D expenses reduce the equity of a firm, which in turn tightens the collateral constraint. Firms can also lose product lines due to obsolescence or creative destruction by competing firms. Accumulation of product lines over time results in endogenous long-run growth.

3.1.2 Production

Consider a firm indexed by $j \in [0, M_t]$ that owns $n_{j,t} \in \mathbb{N}^+$ product lines at time t. Let these product lines be indexed by $i \in \{1, 2, ..., n_{j,t}\}$. At time t and for each product line i, the firm can use physical capital $k_{i,t}$ to produce the final good $y_{i,t}$ according to the technology

$$y_{i,t} = z k_{i,t}^{\alpha} \tag{1}$$

with $z > 0$ and $\alpha \in (0, 1)$. The final good is sold in a competitive market, and its price is normalized to one. Each unit of physical capital has the cost flow $R_t = r_t + \delta$, where r_t is the real interest rate, and $\delta > 0$ is the depreciation rate of physical capital. At time t, the total output of firm i is given by $y_{j,t} = \sum_{i=1}^{n_{jt}} y_{i,t}$, and the total output in the economy is therefore:

$$Y_t = \int_{j=0}^{M_t} y_{j,t}\, dj = \int_{j=0}^{M_t} \left(\sum_{i=1}^{n_{j,t}} z k_{i,t}^{\alpha} \right) dj \tag{2}$$

3.1.3 Innovation, Creative Destruction, Obsolescence, and Firm Exit

Over time, firms can add new product lines to their portfolio through successful innovation, or lose them to obsolescence. Each product line owned by the firm grants the firm the ability to invest resources into R&D to generate a Poisson arrival rate of successful innovation $x_{i,t} > 0$. To generate this arrival rate, the firm incurs an R&D cost flow in terms of the final good given by the cost function

$$C(x_{i,t}) = \chi x_{i,t}^{\phi} \tag{3}$$

where $\chi > 0$ is a scale parameter and $\phi > 1$ determines the convexity. On the other hand, each product line owned by the firm can be lost to obsolescence at the exogenous Poisson arrival rate $\tau^o > 0$, or endogenous creative destruction by other firms $\tau_t^{cd} \geq 0$, resulting in a total rate of $\tau_t = \tau^o + \tau_t^{cd}$. Taken together, at any time t, a firm j with $n_{j,t}$ product lines adds a new product line to its portfolio at the rate $x_{j,t} = \sum_{i=1}^{n_{j,t}} x_{i,t}$, and loses one of its existing product lines at the rate $\tau_t n_{j,t}$. The number of product lines of a firm grows or shrinks over time according to these two forces. If a firm loses its last product line, it exits the economy. Finally, assume that $\Upsilon \in (0, 1)$ fraction of successful product line creations are destructive, and the remaining $1 - \Upsilon$ fraction create a new product line without destroying existing ones.

3.1.4 Financial Frictions and Firm Equity

In this section, financial frictions are introduced into the model. Denote the total capital used by firm j at time t as $k_{j,t} = \sum_{i=1}^{n_{j,t}} k_{i,t}$. Denote the equity of firm j at time t as $a_{j,t}$. At any time t, firm j faces the collateral constraint given by

$$k_{j,t} \leq \lambda a_{j,t} \tag{4}$$

where $\lambda \geq 1$ is a parameter that governs the maximum leverage $k_{j,t}/a_{j,t}$ a firm can have. The proposed specification of the collateral constraint is a common one that is used in Moll (2014) among others. By varying λ from unity to infinity, one can trace out all degrees of capital market efficiency from no capital markets to perfect capital markets. Due to this collateral constraint, firms with sufficiently low equity might produce less output than they otherwise would.

Financial frictions make it necessary to keep track of a firm's equity as a state variable. The equity of a firm evolves according to the ordinary differential equation:

$$\dot{a}_{j,t} = y_{j,t} - (r_t + \delta)k_{j,t} + r_t a_{j,t} - \sum_{i=1}^{n_{j,t}} C(x_{i,t}) \tag{5}$$

The first term is the revenue flow from production. The second term is the cost of using physical capital. The third term is the rent flow from equity. The last term is the cost of R&D. In cases where $k_{j,t} < a_{j,t}$, the firm is lending to other firms in the economy. In cases where $k_{j,t} > a_{j,t}$, the firm is leveraged, and borrowing from others. It is imposed that a firm's equity cannot go below zero.

3.1.5 Firm Entry

At any point in time, there is a continuum of entrepreneurs of measure one who can potentially found a new firm. New firms start with a single product line, and an initial amount of equity $\underline{a} > 0$ must be invested into the firm. In order to generate a Poisson arrival rate e_t of successful firm creation, an entrepreneur must incur an R&D cost flow in terms of the final good of given by

$$C_e(e_t) = \nu \left(\frac{e_t}{M_t} \right)^{\epsilon} \tag{6}$$

where $\nu > 0$ is a scale parameter and $\epsilon > 1$ governs the convexity. Recall that M_t is the measure of firms in the economy at time t. An increase in M_t lowers the cost of new firm creation. A common feature in endogenous growth models, this term is interpreted as knowledge spillovers from incumbent firms to the entrants, and ensures the existence of a balanced growth path equilibrium.[1]

3.1.6 Static Profit Maximization of Incumbent Firms

The static profit maximization problem of the incumbent firm j at time t is stated as:

$$\Pi(n_{j,t}, a_{j,t}) = \max_{\{k_{i,t}\}_{i=1}^{n_{j,t}}} \left\{ \sum_{i=1}^{n_{j,t}} \left(z k_{i,t}^{\alpha} - (r_t + \delta) k_{i,t} \right) \right\} \text{ subject to } \sum_{i=1}^{n_{j,t}} k_{i,t} \leq \lambda a_{j,t} \tag{7}$$

The first thing to notice is that the first order conditions with respect to $k_{i,t}$ for any i are identical, which implies $k_{i,t} = k_{j,t}/n_{j,t}$ for all i; i.e., the total capital used by the firm is split equally across all product lines. If the collateral constraint does not bind, optimality equates the marginal product of capital to its cost, which delivers:

$$k_{i,t} = \left(\frac{r_t + \delta}{\alpha z} \right)^{\frac{1}{\alpha - 1}} \equiv k_t^* \tag{8}$$

The constraint binds when $\frac{a_{j,t}}{n_{j,t}} < \frac{k_t^*}{\lambda}$; or in words, when the equity per product line is insufficiently low to finance operating at the firm's efficient scale. In such cases, the firm levers up to the maximum extent possible, which delivers $k_{i,t} = \lambda \frac{a_{j,t}}{n_{j,t}} < k_t^*$. Note that, regardless of whether the constraint binds or not, the optimal profit flow satisfies:

$$\Pi(n_{j,t}, a_{j,t}) = n_{j,t} \Pi \left(1, \frac{a_{j,t}}{n_{j,t}} \right) \tag{9}$$

3.1.7 Dynamic Profit Maximization of Incumbent Firms

Given the solution to the static problem, the incumbent firm must choose its innovation policies to maximize the value of the firm. Since the static profit flow depends on the number of product lines and equity, these are also state variables in the dynamic problem. Define $V(n, a)$ as the value of an incumbent firm that owns n product lines and has an equity of a. Then the dynamic profit maximization problem of this firm at time t is stated as:

$$\begin{aligned} r_t V(n, a) = \max_{\{x_i\}_{i=1}^{n}} \Bigg\{ & \Pi(n, a) + r_t a - \sum_{i=1}^{n} C(x_i) + V_a(n, a) \left(\Pi(n, a) + r_t a - \sum_{i=1}^{n} C(x_i) \right) \\ + & \left(\sum_{i=1}^{n} x_i \right) [V(n+1, a) - V(n, a)] + n \tau_t [V(n-1, a) - V(n, a)] \Bigg\} \end{aligned} \tag{10}$$

where some subscripts are suppressed for clarity. The first three terms are the static profit, equity rent, and R&D cost flows, respectively. The fourth term captures the influence of the change in

[1] Alternatively, one could assume the mass of entrepreneurs to grow proportionally with the mass of incumbent firms to obtain isomorphic results. One could interpret this as spinoffs from incumbent firms.

equity a on firm value. The fifth term accounts for the change in firm value conditional on adding a new product line as a result of successful innovation, whereas the sixth term accounts for the same conditional on losing a product line to obsolescence.

Similar to the static problem, the first order conditions with respect to x_i for all i are identical, so it can be asserted that $x_i = x$ for all i. The first order condition with respect to this joint x then becomes:

$$(1 + V_a(n, a))C'(x) = [V(n + 1, a) - V(n, a)] \tag{11}$$

The left-hand side is the marginal cost of innovation, and the right-hand side is the marginal benefit. In a model without financial frictions, the term $V_a(n, a)$ would not exist. Its presence captures the fact that investing resources into R&D also reduces equity, which may decrease static profits $\Pi(n, a)$ whenever the collateral constraint binds. This increases the effective cost of R&D for financially-constrained firms. The policy function for x is given by:

$$\hat{x}(n, a) = \left(\frac{V(n + 1, a) - V(n, a)}{\chi\phi(1 + V_a(n, a))} \right)^{\frac{1}{\phi-1}} \tag{12}$$

3.1.8 Entrepreneurs' New Firm Creation Problem

Given the mass M of firms active in the economy, define the value of being an entrepreneur as $W(M)$. The dynamic new firm creation problem of the entrepreneurs at time t is stated as:

$$r_t W(M) - W'(M) g_{M,t} = \max_e \left\{ - C_e(e_t) + e \left(V(1, \underline{a}) - \underline{a} \right) \right\} \tag{13}$$

where $g_{M,t}$ is the growth rate of the mass of firms M_t at time t. The first term in the maximization is the R&D cost needed to found a new firm. The second term is the expected flow value from founding one. If the entrepreneur is successful, it founds a new firm with a single product line, and must invest into the firm an initial amount of equity $\underline{a} > 0$. The optimal policy for e is therefore:

$$\hat{e}(M) = M \left(\frac{V(1, \underline{a}) - \underline{a}}{\nu\epsilon} \right)^{\frac{1}{\epsilon-1}} \tag{14}$$

3.1.9 Interpreting the Model Results and Its Implications

The proposed model combines an endogenous growth model with a financial frictions framework that uses collateral constraints, which leads to some interactions that the two models would not generate in isolation. I will discuss these interactions in the same order as the model is solved.

First, the static profit flow of a firm would only depend on the number of product lines $n_{j,t}$ without a collateral constraint. Its introduction reduces the profit flow of the firm when the constraint binds, resulting in a profit stream that depends both on the number of product lines, $n_{j,t}$, and the equity per product line, $a_{j,t}/n_{j,t}$, since the maximum capital that can be used in each product line is $k_{i,t} = \lambda \frac{a_{j,t}}{n_{j,t}}$. Statically, this resulting inefficiency is the same as that found in standard models with financial frictions: To maximize static output, a social planner would distribute capital equally across all product lines, since they all share a common productivity z; i.e., $k_{i,t} = K_t/N_t, \forall i$. Any dispersion away from this allocation reduces the level of output. Different from standard models with financial frictions, the dispersion also affects the dynamic decisions of the incumbent firms and entrepreneurs, which I will discuss next.[2]

Consider the dynamic innovation decision of the incumbent firms, and the associated first order condition given in equation (11). If the collateral constraint was removed, the first order condition would simply read:

$$C'(x) = [V(n+1) - V(n)] \tag{15}$$

instead of

$$(1 + V_a(n,a))C'(x) = [V(n+1,a) - V(n,a)] \tag{16}$$

The first difference is seen on the marginal benefit side. Since the static profit flow depends not only on the number of product lines n, but also on whether there is enough equity a to rent a sufficient amount of physical capital, firms with different amounts of equity per product line a/n face a different marginal benefit from expanding into a new product line, despite the fact that its productivity is homogeneous at z for all firms and their product lines. Consequently, although the social value of expansion into a new product line is the same, firms face different private marginal benefits due to the dispersion in a/n across firms. This constitutes a dynamic inefficiency, where firms can under- or over-invest in expansion compared to what a social planner would choose. To provide a real-world example, consider a firm with very low equity per product line a/n compared to the economy average. From a dynamic efficiency point of view, we would want this firm to invest into expansion as much as any other firm. However, since this firm's a/n is low, the new product line would be worth much less in private, as the firm does not have the funds to spare to finance production. This reduces innovation by highly financially constrained firms, whereas financially unconstrained firms might invest too much in innovation, as their private benefit might even exceed the social benefit a planner would consider. Taken together, these results suggest that financial frictions can decrease both overall spending on innovation (private benefits < public

[2] Note that the dispersion of a/n in the basic model only owes to the randomness in gaining new product lines conditional on successful innovation, and losing them due to creative destruction. In reality, firms face additional volatility in earnings unrelated to innovation. The model can be extended to capture these additional channels that generate further dispersion in a/n, such as assuming that the productivity constant $z > 0$ follows a Markov process as in Ocampo-Diaz and Herreno (2021), introducing capital depreciation shocks as in Jungherr, Meier, Reinelt, and Schott (2020), or other Poisson events that represent unexpected cash inflows and outflows in general.

benefits), and misallocate innovation spending across product lines and firms given a fixed amount of spending (public benefit is homogeneous, but private benefits are dispersed due to the cross-firm dispersion in a/n).

The second difference is seen on the marginal cost side. In the absence of financial frictions, the term $V_a(n,a)C'(x)$ would not be present. This term captures the fact that investment in R&D steals away resources that could be used to finance production. Each dollar spent on expanding into new product lines reduces the equity of the firm, and if the collateral constraint is binding, this reduces firm value because, going forward, the firm will need to rent less capital than it otherwise would. This extra term is less troublesome for firms that already have enough equity to finance their production. But for highly constrained firms with a low a/n, the private cost they face is also higher than it should be. In other words, the dispersion in a/n across firms creates a dispersion in the private marginal cost of innovation that wouldn't exist in a model without a collateral constraint. This means the innovation incentives of firms with low equity per product line are hurt on both accounts: their private benefits from expansion are lower than socially optimal, and their private cost to do so is higher than socially optimal. The dispersion in a/n can therefore also depress overall innovation, and misallocate it across firms due to the dispersion in private marginal costs.[3]

Finally, the financial frictions also affect the entrepreneurs' decision to found new businesses. In a model without the collateral constraint, the new firm would simply be worth $V(1)$. In the current model, it is worth $V(1,\underline{a}) - \underline{a}$. To the extent the initial equity per product line $\underline{a}$ is lower than k^*/λ, the initial profit flow will suffer until the firm can build up its equity. Furthermore, the need to finance both R&D and future production using equity also depresses the equilibrium value of the firm value function $V(n,a)$ itself due to a lower option value arising from the possibility of future expansion. Consequently, the inequality $V(1,\underline{a}) - \underline{a} < V(1)$ holds for any finite value of $\lambda > 0$.[4] Overall, the financial frictions reduce the initial value of new businesses, and lower new business entry, and consequently, both business dynamism and economic growth.

[3] It also bears mentioning that the model with financial frictions can generate under-investment in innovation compared to the first-best under no financial frictions even in the absence of dispersion in a/n when the total amount of funds available is sufficiently low. In such a scenario, the constraint would bind for all firms simultaneously, and all firms would under-invest. The dispersion in a/n causes further under-investment in total innovation as a result of misallocating the limited amount of funds available. This is akin to how a positive average markup with no markup dispersion still generates a reduction in output, whereas dispersion in markups generates misallocation of inputs and further depresses total output in models with imperfect competition in the product market.

[4] To see why this is the case, first note that $V(1,a) - a \leq V(1)$ is true for any a. The subtraction of a eliminates the rent flow ra, and the cash flows on both sides become static profit flow minus R&D cost. As shown in Section 3.1.6, $\Pi(n,a) \leq \Pi(n)$, since $\Pi(n)$ is the value where firm can pick the optimal k^* without any constraints. For any finite value of $\lambda > 0$ and any a, there exists $n \in \mathbb{N}^+$ such that $\frac{a}{n} < \frac{k^*}{\lambda}$, i.e., the constraint binds, and we have $\Pi(n,a) < \Pi(n)$. The probability that a firm can reach n product lines over a finite period of time T is always strictly positive under positive R&D spending, which $C'(0) = 0$ guarantees. Since the constraint strictly binds over a positive measure of future histories given any finite $\lambda > 0$, we conclude $V(1,\underline{a}) - \underline{a} < V(1)$. As one eliminates financial frictions by taking the limit $\lambda \to \infty$, the left-hand side converges to the right-hand side.

3.2 Relating the Results to the Existing Literature on Financial Frictions

How do the results obtained from the proposed model mesh with and compare against what we already know from earlier work on financial frictions? What new insights do we obtain by endogenizing productivity growth? Are there any lessons from the existing literature that do not hold anymore?

To answer these questions, it helps to remember how firm productivity is modeled in the existing literature on financial frictions and firm investment. In general, there are two approaches. One is to draw a firm's productivity from a fixed distribution such as the Pareto distribution, after which it either never evolves, or is redrawn from the same distribution with some probability as in Buera and Shin (2013). Another approach is to assume that the firm's productivity evolves according to an exogenously-specified Markov process as in Moll (2014), which is commonly chosen to be a first-order autoregressive process (AR(1)). Some papers such as Midrigan and Xu (2014) combine the two approaches, where the productivity of a firm has both a permanent component and a persistent yet stochastic one (finite-state Markov process).

The common factor in all approaches is that the evolution of a firm's productivity is exogenous, and it cannot be influenced by the firms or the government. There can be heterogeneity in firm investment in capital, entry, and exit based on firm productivities, government policy can influence these investments and change the selection of firms, and consequently, total factor productivity and total output can change. However, there is no feedback in the reverse direction, and therefore no effect of financial frictions on the evolution of productivity and the resultant firm dynamics. The simple model outlined above shows that (1) financial frictions can cause dynamic under-investment in innovation as well as misallocation of innovation spending across firms, which leads to a permanent drop in the growth rate of output and firm entry, as opposed to the static level effect present in existing models, and (2) the need to spend resources on innovation itself reduces firm equity, and tightens the financial constraint of the firm, creating a feedback loop between a firm's investment in intangible and tangible capital. Since the welfare impact of even a small change in the growth rate of output tends to be substantial under common preferences, existing studies might be under-estimating the negative impact of financial frictions at the aggregate level in the long run.

Another point of deviation is the rate at which firms can reach their efficient scale, if ever. A key lesson from the existing literature on financial frictions and firm investment is that, over time, firms can "save themselves out of the constraint". Consider a model where a firm draws a permanent productivity level from an exogenous distribution. Then, there exists a level of equity a^* with which the firm can attain its efficient scale k^*. Firms may start out with insufficient equity, but over time, they can build up their equity so that the constraint no longer binds. In such a world, from the firm's perspective, financial constraints are a transitory problem, and at the aggregate level, it is only a problem to the extent that existing firms are replaced by new firms with insufficient equity.

The same lesson holds for models with a highly persistent Markov process for productivity.

By comparison, the efficient scale of a firm in the proposed model with endogenous growth is ever-increasing conditional on firm survival. It is not permanent, and there is no mean-reversion as would be the case for an AR(1) process. There is a permanent race between equity and the number of product lines. A firm that has high success in innovation finds itself routinely underfunded, as n grows ahead of a, and the financial constraint tightens.[5] A firm that is not successful in innovation or loses its product lines to creative destruction can attain its efficient scale, but receives a lackluster return on its excess equity, and is less profitable. Consequently, financial frictions become a permanent problem for all firms, rather than a transitory one, influencing their output and investment decisions throughout the firm life-cycle. At the aggregate level, older firms that had some time to build up their equity might still have binding collateral constraints if they had a growth spurt, amplifying the traditional static negative effect on total factor productivity and output in existing models.

To sum up, financial frictions, which were already recognized as a significant problem for aggregate productivity, might be even more detrimental for welfare if we take the endogenous firm investment in productivity into account. A quantitative investigation of how much the addition of the innovation margin matters seems to be a worthwhile research avenue.

3.3 Policy Implications, Further Considerations, and Alternative Solutions

The proposed model demonstrates that even in a simple setting with firms that are ex-ante homogeneous in their productive and innovative efficiency (same z, χ, and ϕ), financial frictions in the form of a collateral constraint can generate significant dynamic inefficiencies in the form of lower overall innovation, misallocation of R&D inputs across firms, and lower firm entry and business dynamism. Financially constrained firms operate below their efficient scale, as well as invest less in innovation.

Directly tackling this problem would necessitate micro-management of firms' capital allocation or their equity levels, which cannot be easily accomplished in a decentralized economy. A less direct solution would be to address the underinvestment problem in innovation by differential R&D subsidies to firms contingent on observables that are correlated with their ability to fund their operations and research. In most countries, a significant portion of subsidies to research and development are not state-contingent – in other words, "one-size-fits-all" policies are predominant. However, we know that small and young firms face a higher difficulty in financing their operations and research since they did not have the time to build up their equity and "save themselves out of the constraint". Firms also differ in their access to equity finance, where publicly-listed firms can ameliorate the problem by directly issuing new shares rather than relying on debt financing.

[5] This problem is further magnified if firms are heterogeneous in their innovative efficiency χ, which is discussed in the next section.

It should then be possible to design R&D policies that favor more financially constrained firms by favoring smaller and younger, private firms over well-established firms with easy access to debt and equity financing. While imperfect, such policies can still be welfare-enhancing.

It should also be kept in mind that the simple model abstracts away from many features such as heterogeneity in firms' efficiency in innovation. If some firms were to be more efficient in innovation, they would be able to come up with more product lines during the same span of time, and that would further exacerbate the problem they face, as building up equity internally would be even harder, and their equity per product line would be lower. Their build-up of internal equity would simply not catch up to the speed at which they innovate. Another simplifying assumption is that all firms face the same collateral constraint. Taking the model seriously, this would mean all firms would lever up to the maximum amount allowed when the constraint is binding. However, firms' leverage ratios show great variation for private firms, as found in Dinlersoz, Kalemli-Ozcan, Hyatt, and Penciakova (2018). Not only do small and young private firms have little equity, but they may also face tighter limits on their possible leverage ratios, once again exacerbating the inefficiency.

Fortunately, there are also alternative solutions to circumvent or alleviate the negative effects of financial constraints on firm innovation. One method is to go public, so that the firm can use equity financing, as discussed before. However, going public is not without its costs, and the reduced concentration in firm ownership can aggravate the potential agency frictions between the owners and the managers, making corporate governance a potential concern. In particular, a manager might choose a suboptimal rate of innovation compared to what the firm's shareholders (or the society) prefer. Aghion, Van Reenen, and Zingales (2013) find that the presence of institutional owners among shareholders plays a key role in promoting innovation by better alignment of manager incentives. Celik and Tian (2021) find that managerial compensation structure is the key mechanism through which institutional ownership affects firm innovation. Institutional investors reduce the manager's influence over the determination of his contract, which results in a package richer in stock options, incentivizing a higher innovation rate which is better for shareholders and the society alike. Despite this alleviating effect, the agency frictions are found to remain substantial, the removal of which may increase growth by 51 percentage points and welfare by 7.1%.

Another potential solution is venture capital (VC) and angel investors. The importance of VC in the US economy has surged over the past 50 years, from roughly $300 million in 1970 to $54 billion in 2015 (using 2009 dollars). While a tiny fraction of firms have access to VC, the selected companies frequently become superstar firms, including household names such as Apple, Microsoft, Google, Amazon, and so on. Greenwood, Han, and Sanchez (2018) investigate the relationship between venture capital and growth using an endogenous growth model incorporating dynamic contracts between entrepreneurs and venture capitalists, and find that VC significantly boosts innovation, productivity and employment growth, and welfare. Ates (2018) develops a dynamic general equilibrium model that incorporates an explicit VC market with search frictions, featuring endogenous selection and operational knowledge transfer between the VCs and the firms, and finds that one third of the VCs positive impact on economic growth arises from the operational knowledge channel. Akcigit, Dinlersoz, Greenwood, and Penciakova (2019) examine the VC market both empirically and theoretically, and find that the presence of venture capital, the degree of assortative matching between VCs and firms, and the taxation of VC-backed startups matter significantly for productivity growth.

Finally, if a firm does not have the resources to properly commercialize its new ideas, it can also be possible to transfer the ideas across firm boundaries. There are various methods through which ideas can be reallocated across firm boundaries, such as licensing and patent sales. In more extreme cases, a firm can choose to completely acquire another one in order to obtain both the target's patent portfolio, and its existing assets and employees who possess the necessary familiarity with the ideas embedded in these patents. This reallocation of ideas through patent sales and mergers and acquisitions will be the topic of the next section.

4 Acquisition and Reallocation of Ideas, and Synergistic Mergers

The generation of ideas can be a serendipitous process. New ideas may not always occur to their best potential users. In some cases, this might simply be due to the innovator not having sufficient funds to translate it into a new service or product, as discussed in the previous section. At other times, it might be an issue of technological fit. The incarnation of an idea requires a vision or an application, and the know-how to implement it, which are often possessed by those who work in areas related to the end-use of an idea. Firms often develop ideas that are not close to their primary business activity, in which case transferring the idea to another firm with a better technological fit can generate positive value. This necessitates a market for ideas, where economic agents can buy and sell innovations, which has the potential to allocate ideas more efficiently.

A glimpse at the patent assignment data from the United States Patent and Trademark Office (USPTO) reveals that this is definitely not a rare phenomenon. Among all patents registered between 1976 and 2006 in the United States, 16% are sold at least once, and this number goes up to 20% for domestic patents. These high ratios are observed despite the fact that they do not include technology transfers through licensing agreements, or wholesale transfer of patents as a result of mergers and acquisitions. On the whole, these numbers suggest an active market for ideas in the United States.

Some natural questions to ask are how efficient the market for ideas is, and what the macroeconomic impact would be if its efficiency could be further improved. Akcigit, Celik, and Greenwood (2016) conduct an empirical analysis of patent sale micro-data in the United States, and develop a search-theoretic model of the market of ideas with endogenous growth, which is aimed to answer these questions.

The empirical findings lend credence to the story of technological fit: Patents are found to contribute more to a firm's stock market value if they are technologically closer to the owning firm – i.e., the technological distance between the patent and the firm's previously invented stock of patents, as captured by the citation frequencies between different technology classes, is lower. This finding indicates that incorporating ideas that are technologically closer to a firm's field of expertise yields higher benefits as captured by firm value. Consistent with this finding, firms are found to be more likely to sell a patent to another firm if it is technologically distant. Conditional on a patent sale, it is also true that the patents are technologically closer to their buyers than their sellers, indicating that patent sales improve the technological fit between ideas and their owners on average.

The market for ideas, however, is not without its problems. For economic progress, both the possibility and the speed of exchange are important. Buying and selling intellectual property is a difficult activity, as each patent represents a unique idea. It is not always readily apparent who the potential buyers and the competing sellers are, especially in situations where firms desire to keep their business strategies secret. Information asymmetry between the inventor of an idea and the potential buyers can also lead to further frictions where the buyers need to spend time and resources to assess the true value and technological fit of an idea. As a result of all these complications, the market for patents is found to be substantially illiquid, where the sale of a patent takes 5.5 years on average, with a large standard deviation of 4.6 years.

Akcigit, Celik, and Greenwood (2016) estimate their structural model to fit the abovementioned facts, and gauge the efficiency of the market for ideas. Its contribution to growth and welfare is found to be significant even under conservative assumptions. The calculations indicate that if the market for ideas were shut down, long-run growth would go down by 6 basis points, with a 1.18% consumption-equivalent welfare loss, despite the fact that the shutdown triggers increased in-house R&D to compensate. The gains from a more efficient market for ideas are found to be much more substantial. Allowing the sellers to find the perfect buyers through directed search increases growth by 11 basis points, and welfare by 2%. Increasing the contact rate to its maximum value – i.e., removing the huge delay in patent sales by increasing the matching efficiency – boosts growth by 94 basis points, which translates to a tremendous 14% gain in consumption-equivalent welfare. These findings suggest that there is significant room for improvement in the efficiency of the market for ideas, although the exact methods to do so remain elusive.

The market for ideas interacts closely with firm finance. The simple model in the previous section highlighted how financially constrained firms might not be able to exploit their new products to their fullest extent even if technological fit was not an issue. Chiu, Meh, and Wright (2017) develop a theoretical model where this idea is taken to the extreme: Inventors can conduct R&D and come up with new inventions, but they lack the ability to commercialize them. Instead, they must sell their ideas to entrepreneurs who can use them in production. Entrepreneurs, on the other hand, must have cash on hand in order to buy an idea, which implies financial frictions can hinder the efficiency of the market for ideas. A quantitative investigation of the magnitude of this effect might be a fruitful research avenue.

The interaction can also be in the opposite direction: while patents are harder to appraise and transfer than tangible assets, they can still be used as collateral, even if highly discounted due to the illiquidity of the market for ideas. Previously invented ideas can therefore act as collateral, and relax the financial constraints a firm faces. Akcigit, Celik, Itenberg, and Ordonez (2016) document that around 10% of patents granted by the USPTO between the years 1980 and 2006 were pledged as collateral to secure credit at least once. This pledging intensity, on the other hand, is found to be quite heterogeneous across patent technology classes. Looking at the problem from a lender's point of view, the value of a patent as collateral hinges on the ease with which it can be liquidated in the case of a default. Liquidation, in turn, is easier if the patent market for the technology is more active. Consistent with this line of reasoning, it is found that the pledging intensity is higher in technology classes with a more active secondary market for patents, as captured by the number of potential buyers, and the rate at which patents are bought and sold. This has further implications for the direction of technical change, as financial frictions are less severe in industries with more active patent markets, which is associated with higher firm entry and investment.

As mentioned before, another way ideas can be transferred between firms is the wholesale acquisition of one firm by another, instead of buying the patents piecemeal. Mergers and acquisitions are observed very frequently in industries such as healthcare and information and communication technologies, where startups consider a profitable acquisition as a successful end-goal. Even among large public companies that engage in innovation, M&A is quite common: among publicly-listed US firms that had at least one patent between the years 1980 and 2006, the annual probability of being acquired by another such firm is 1.91%. However, this market for wholesale acquisition of ideas through M&A is as ridden with frictions as the market for patents, if not moreso, as acquirers find it challenging to assess the value of innovative targets under asymmetric information.

There are three aspects to consider: First, even if one ignores the additional difficulties inherent in appraising the intellectual property of target firms, finding a good target for M&A and conducting due diligence along more standard dimensions is a long and arduous process. David (2021) develops a search and matching model of mergers and acquisitions in general equilibrium, and uses it to evaluate the implications of merger activity for aggregate economic outcomes. In this framework, firms are heterogeneous in terms of their productivity, which is persistent outside M&A, but changes endogenously according to a synergistic merger technology in the case of an acquisition. It is found that the efficiency of the M&A market contributes significantly to the level of aggregate output and consumption.

The second and third aspects to consider are the difficulties in the evaluation of IP under information frictions, and how the activity in the M&A market affects the endogenous decisions of firms to innovate. Celik, Tian, and Wang (2020) develop and estimate a structural model of acquiring innovative firms under information frictions, featuring endogenous merger, innovation, and offer composition decisions. Different from David (2021), the information asymmetry is explicitly modeled, where acquirers face adverse selection risk due to the private information of the targets regarding the value of their own innovation. To quantify and discipline the effect of information frictions on M&A between innovative firms, Celik, Tian, and Wang (2020) rely on three empirical observations that shed more light on the interaction: First, the takeover exposure of firms is found to follow an inverted-U shape rather than an increasing relation in firm innovation stock, as more innovative firms are more challenging to appraise, and the high adverse selection risk manifests as partial market failure. Consistent with this observation, more innovative targets are more likely to turn down bids, indicating more cautious offers by acquirers due to the possibility of "lemons" accepting them, as in Akerlof (1978). Finally, in order to mitigate the adverse selection risk in part, acquirers can choose to make an offer that consists of more equity compared to cash so that the target shareholders also have some skin in the game. It is observed that the equity share of offers increases with target innovativeness, consistent with the theory. The model matches these regularities to gauge the magnitude of information frictions via indirect inference.

The quantitative results suggest that the information frictions in M&A are substantial. Specifically, it is estimated that due diligence by the acquirers helps reveal only 30% of the private information possessed by the targets, and thus, acquirers face severe adverse selection risk in purchasing innovative targets, creating substantial barriers to trade. Eliminating the information frictions is predicted to increase capitalized expected gain from M&A by around 60%. A more efficient M&A market also has an indirect effect on firm innovation, increasing average R&D intensity by 10%. The average productivity level increases due to an increase in both quality and quantity of M&A, as well as innovation, which results in a permanent 3% increase in output and social welfare.

There is, of course, also the "dark side" of M&A. While the abovementioned papers focus on the synergy gains of M&A from reallocating ideas across firm boundaries, they do so under the assumption of perfect competition. In reality, a firm might want to acquire another due to anticompetitive reasons, such as reducing current competition to increase its current market share, markups, and profits; or reducing future competition by buying out innovative rivals while they are still small – the so-called "killer acquisitions" as in Cunningham, Ederer, and Ma (2021). Consequently, the antitrust authorities have to weigh the potential synergy gains from mergers against their anticompetitive impact on static product market competition, as well as dynamic competition in innovation. Cavenaile, Celik, and Tian (2021) build a unified framework that combines and generalizes the Schumpeterian step-by-step innovation framework with static oligopolistic competition models such as Atkeson and Burstein (2008) or Autor, Dorn, Katz, Patterson, and Van Reenen (2020), and dynamic industry equilibrium models as in Ericson and Pakes (1995) to study the effectiveness and the macroeconomic impact of antitrust enforcement in the United States. It is found that the existing antitrust policies do indeed promote growth and welfare, and that more stringent policies can boost these gains substantially. Interestingly, the dynamic effects of antitrust enforcement on growth and welfare are found to be an order of magnitude more important than the traditionally-studied impact on static allocative efficiency through the reduction of markups and market concentration. The primary benefits of increased antitrust enforcement come through the reduction of the rate at which anti-competitive mergers occur, in which large superstars preemptively acquire innovative firms that can be potential rivals in the future. These anti-competitive mergers ensure the dominance of the incumbent firms, which reduce their innovation drastically after the acquisition, since they do not face intense dynamic competition anymore. These results highlight the importance of considering the dynamic effects in the regulation of industries: without taking innovation into account, evaluation would be constrained to the static analyses of the 1970s, which culminated in the seemingly out-of-date HHI-based antitrust policy guidelines followed by the Department of Justice and the Federal Trade Commission. New guidelines that directly target anti-competitive acquisitions and pay more attention to dynamic competition in innovation compared to static product market competition are likely to yield substantial gains in growth and welfare.

5 Conclusion

As the previous sections demonstrate, there are numerous bottlenecks in the process through which new ideas are discovered, reallocated, implemented, and utilized, which eventually culminates in higher growth and welfare. The identification of these bottlenecks and their policy implications has been a very active research area in the past three decades, which owes its existence to the voluminous seminal contributions on creative destruction, endogenous growth, and firm dynamics by Philippe Aghion and Peter Howitt. Our work as economists, however, is far from complete. Many important questions still remain unanswered, and direct solutions to most of the highlighted inefficiencies are yet to be found. It is likely to remain an active field of research in the foreseeable future.

Beyond the intellectual value of gaining a better understanding of these economic processes, the real-world application of the insights obtained can have far-reaching consequences. Slight changes in the rate of economic growth can deliver tremendous improvements in living standards over long periods of time, and therefore, the benefits to resolving the various inefficiencies that plague the process of innovation can justify large investments in time and resources.

It should be noted that many laws, regulations, and government policies that influence technological progress across the world were designed before the advent of the growing literature on endogenous growth and creative destruction. As is the case for antitrust regulation, many such policies are predicated on earlier economic models in which the long-run dynamics are lacking or altogether absent. The duty therefore falls to us to make the policymakers and the broader public aware of the advances in our understanding, and refine the policy implications that arise as a consequence. It is my hope that this combined volume will succeed in contributing towards this goal.

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