Crisis Innovation*

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Abstract

In a differences-in-differences design we provide the first systematic evidence that distress from the Great Depression drove the single largest shift in innovative organization in U.S. history – from predominantly outside to inside the firm. Parallel trends prior to the shock, evidence of a drop within every major technology class, and consistent results using distress driven by commodity shocks all suggest a causal effect of local distress. Despite this decline in patenting, innovation is quite resilient, with inventors moving into firms and the average quality of surviving patents rising so much there is no observable change in aggregate future citations.

JEL Classifications: G01, G21, O3, N12, N22, N32

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"Many firms [of the 1930s] run by inventor-entrepreneurs were either acquired or driven out of business"

Landes et al. (2012)

"1929-1941 were, in the aggregate, the most technologically progressive of any comparable period in U.S. economic history"

Field (2003)

The biggest financial crisis of the past century – the Great Depression – was coincident with the single largest shift in the organization of innovation in U.S. history from predominantly outside to inside the firm. Prior research has emphasized the importance of technological change as a primary driver of this transition (Mokyr 1990, 2002, Mowery and Rosenberg 1999, Jovanovic and Nyarko 1994), but there is no systematic empirical evidence of the direct role, if any, played by distress in the aftermath of the Great Depression.[1]

In addition to being critical for our understanding of the development of the U.S. economy, this period provides a unique opportunity to study the long-run role crises can play in shaping innovation. On the one hand, a crisis may create important setbacks in the production of innovation and a "missing generation" of highly productive entrants which could reduce business dynamism and growth (Hall 2015; Gourio et al. 2016; Akcigit and Ates 2019). On the other hand, distress periods may represent an opportunity to reshape innovation efforts towards more efficient organizational forms and higher-impact projects (Schumpeter 1942; Caballero et al. 1994; Manso et al., 2019). Unfortunately, empirical evidence on this question is challenging to obtain in the modern period. Firm dynamics are slow moving (Luttmer 2012) making it generally difficult to evaluate the long-term response to an event as recent as the Great Recession. Furthermore, in modern time innovative activity, and especially technological entrepreneurship, is geographically concentrated (Guzman and Stern 2016), making it hard to find meaningful variation that could be used to study the effect of local distress shocks on innovation ecosystems.[2] By contrast, prior to

[1]This is despite anecdotal and case-based evidence that the crisis may have shifted the innovative activities of technically-inclined graduates (Lamoreaux and Levenstein 2017).

[2]While Bernstein, McQuade, and Townsend (2019) are able to use shocks to the wealth of individual inventors working at the same firm to look at how wealth can alter innovation, our focus is shocks to local capital provision to technological entrepreneurs, not the wealth of inventors at existing firms. As is shown in our paper firms themselves at a local level appear to have relatively muted effects, suggesting some amount of transfer either across firms, across organizational form, across geography, or within firms. In that respect our analysis is at the local "general equilibrium" level, allowing for within region offsetting or exacerbating effects, that likely include in them partial equilibrium phenomena highlighted in Bernstein, McQuade, and Townsend (2019). By contrast in the period surrounding the Great Depression financing was a more localized affair because of regulatory and technological constraints (Nestor 1992; Mitchener and Wheelock 2013). When banks failed, this caused massive local financial disruptions.

the 1930s innovation outside the firm was the predominant form of patenting so pockets of technological entrepreneurship, supported by secondary markets for patents and local capital, were ubiquitous across the U.S. (Lamoreaux et al. 2009). Therefore, the size of the shock and the relative widespread distribution of innovation activity within the US makes this period an ideal setting in which to evaluate the long-run effects of crises on innovation.

This paper studies the importance of the Great Depression in explaining the contraction in technological entrepreneurs. To answer this question, we develop a new measure of technological entrepreneurship based on independent patenting and spanning more than a century, and we use a differences-in-differences design to compare counties with variation in bank suspensions in the 1929-1933 period, as a proxy for local economic distress. This specification also includes state-time fixed effects to flexibly control for contemporaneous changes in state-level policies and local business cycles. We find that direct effects of disruptions from this crisis predicted a sudden and persistent decline of more than 10% in patenting by technological entrepreneurs, but no aggregate local effects on firm patenting. Combining these two margins, the shock led to an local decline in total patent production not explained by aggregate national changes in technology, regulation, or costs of incorporation. The relative difference in the effects of distress by organizational form is large enough to explain as much as 11% of the total decline in the proportion of patenting done outside the firm. This evidence suggests that - while other factors, such as technological change, likely constitute the major drivers of this transition - the direct effects of the crisis itself also likely played an important role. Parallel trends prior to the shock, no reduction in firm patenting, and evidence of a drop within every major technology class suggests effects are causal and unlikely to be driven by reverse causality.

Using a variety of tests, we show that our results are not driven by a decline in the local demand. For example, the growth in local retail sales during the Great Depression—the key variable used to measure local demand shocks (Fishback et al. 2001)—does not predict significant changes in local innovation. Instead, the results are more likely explained by the effects that bank distress has on local financing. On the one hand, this channel may not be surprising since sources of capital for developing innovation were local, but secondary markets for technology and patents were national in scope (Lamoreaux and Sokoloff 2001a). On the other hand, however, this result may appear puzzling, because banks themselves weren't the dominant direct source of capital for independent inventors (Lamoreaux et al. 2006). One possible explanation is that the contraction in banks' activity is connected with a reduction of capital that is available to local investors in new ventures. As suggested by the previous research (Lamoreaux et al., 2006), independent inventors heavily relied on local wealthy individuals to raise the capital that was necessary to develop their technology and bring them to the market. In our period, distress in the local banking sector was intimately tied to the fortunes of local wealthy investors therefore reducing the ability of these individuals to invest directly in new technology ventures and perhaps permanently disrupting these networks. Not surprisingly, the comprehensive direct measures of changes in the wealth of local investors are not available, but we do know that wealthy individuals likely to provide capital for independent inventors typically had substantial investments in local real estate. Rajan and Ramcharan (2015) and Jaremski and Wheelock (2018) have shown that commodity price changes following WWI can be used as an instrument for changes in local property values during the Great Depression. Using that as an instrument, we show that shocks to proxies for local wealth also appear to predict changes in technological entrepreneurship as well as increased bank distress. This is consistent with wealth of local capital playing a critical role in the shift in organizational form caused by the Great Depression. The use of shocks in commodity prices following WWI instead of bank distress in the early 1930s also provides additional evidence that our overall findings are not driven by reverse causality.

We also find that even though the crisis itself was relatively short-lived, the effects on organizational form appear to be permanent—lasting for every decade for the next 80 years. In fact, our new measure of technological entrepreneurship also allows for a consistent definition of technological entrepreneurs across more than a century. Therefore, even if distress from the Great Depression were only a catalyst for changes already on the horizon, this lack of "catching-up" by distressed counties suggests that the shock had important distributional effects. This evidence on persistence is also consistent with the idea that large shocks can lead to equilibria shift in the organization of innovation. In this case, the idea is that the reduction in activity by technology entrepreneurs may have led to a dissolution of other important aspects of the local ecosystems, such as markets for patents and patents agents, that helped facilitate the transfer of capital from local wealthy individuals to independent inventors (Lamoreaux et al., 2006). Such systems/networks can exist as an equilibrium, but also devolve into equilibria where patenting moves into firms when faced with disruptions to technological entrepreneurs (Aghion and Tirole 1994, Gromb and Sharfstein 2002, Hellmann 2007). For example, while many regions in the modern U.S. would love to develop into Silicon Valley, perhaps not surprisingly, moving to an equilibrium where the local environment supports that sort of technological entrepreneurial activity is not simple.

The massive decline in patenting by independent inventors (technological entrepreneurs) is concerning for innovative activity since these weren't just meaningless patents developed for the inventors own enjoyment or consumption. Akcigat et al. (2017), Nicholas (2010), and Lamoreaux et al. (2009) have all noted that the average quality and impact of these patents was larger than for the average firm patent. In fact, more than one-third of independent patents filed at this time were cited by patents filed more than 50 years later (Lamoreaux et al. 2009). Given these findings one might naturally conclude that crises are likely to be purely destructive forces for innovative activity. Despite the negative effects on independent patenting, our evidence shows that innovation during crises can be more resilient than it may appear at a first glance. First, the average quality of surviving patents rises so much that there is no observable change in the aggregate future citations of these patents, in spite of the decline in the quantity of patents. A major benefits of looking at the Great Depression is that we can see all future patents even 80 years later and these gained citations don't mean-revert. Second, the shock is in part absorbed through a reallocation of inventors into established firms, which overall were less affected by the shock. In the short-run firms show little effect on their citation activity, but over the long run, firms in more affected areas compensate for the decline in entrepreneurial innovation and produce patents with greater impact. Third, the results reveal no significant brain drain of inventors from the affected areas. This is surprising, given some evidence of relatively high mobility among inventors at this time period (Akcigat et al. 2017 and Sarada et al. 2019). However, the null result of bank distress on inventor mobility likely suggests that the crisis constrained geographic mobility of even a relatively mobile group. Overall, our findings suggest financial crises are both destructive and creative forces for innovation, and we provide the first systematic evidence of the direct role distress from the Great Depression, rather than technological change or regulation, played as a catalyst in this unprecedented structural shift in the nature of innovation.

These results complement and help reconcile a growing literature examining the effects of economic distress on innovation. Nanda and Nicholas (2014) show that among firms owning R&D labs prior to the Great Depression, firms more reliant on external financing experienced relative declines in the quantity and the quality of patenting if they were located in counties with larger bank distress.[3] At their surface these results seem in contrast to evidence in Field (2003) and Kelly et al. (2018) who emphasis the

[3]Huber (2018) finds similar firm-level effects in a more modern setting. Huber (2018) exploits variation in German firms' exposure to a large bank's lending cut, and finds that more exposed firms experienced larger decline in patenting

aftermath of the Great Depression as one of incredible technological progress and innovation. Our focus help to provide some reconciliation between these results. To the extent that independent inventors are entities particularly dependent on external financing, our results are consistent with Nanda and Nicholas (2014) and therefore extend their mechanism also outside traditionally defined established firms. However, independent inventors cannot simply be considered a special type of established firm. Similar to today's start-ups, independent inventors were organizations distinct from established firms that differed from them in terms of strategy, funding methods, and scope. So perhaps not surprisingly, we find some critical differences in the response of independent patenting from those for established firms in Nanda and Nicholas (2014). In particular, we find that more externally finance dependent organizations, in our case independent inventors, experienced a much larger decline in the quantity of patenting in regions with bank distress. However, while Nanda and Nicholas (2014) find a matching reduction in the quality of the firms' innovation, we find exactly the opposite among independent inventors. Furthermore, we also find evidence that even the overall decline in patenting quantity in areas with more distress was, at least partially, offset in the long-run by a transition of organizational form. These cross-organizational migrations help explain the relatively muted local aggregate response by firms (Field 2003), despite observed declines in Nanda and Nicholas (2014) at the established firm level and rise in the quality of surviving innovation. In that respect our findings are consistent with work by Lamoreaux et al. 2009 who shows specific instances when distress from the Great Depression led to shift of recent potential technological entrepreneurs, graduates of Case Western University, into firms.

While modern patenting is dominated by within-firm advancements, that organizational structure of innovation, as we have noted, is neither historically ubiquitous (Nicholas 2010; Kenney 2011; Landes et al. 2012) nor clearly theoretically dominant (Aghion and Tirole 1994; Gromb and Sharfstein 2002; Hellmann 2007). In our main analysis, we focus on the overall innovative activity by independent inventors. During this period, independent inventors are in many dimensions akin to technology entrepreneurs today (Lamoreaux and Sokoloff 2001b; Nicholas 2010). In fact, similar to start-ups today, independent inventors were early-stage organizations that developed new technologies in order to raise money either from external investors or sell the technologies to larger firms. Importantly, independent inventors—both quantitatively and qualitatively—were not minor players in this space, but were at the forefront of the technological frontier of the time and, by many metrics, the largest organizational form of innovation at this time (Nicholas 2010). In this context, we think of this analysis as speaking to the extent to which the local financial distress can affect long-run business dynamism. This is a concern that has grown in interest following declines in new firm entry (Bassetto, Cagetti and De Nardi (2015); Siemer (2016); Moreira (2017)), slow-downs in technological advancement, (Hall 2015), and declines in productivity (Duval et al. 2019) in the aftermath of the Great Recession. These sorts of concerns in the fallout from major financial crises are not new however. In fact Schumpeter (1942) consideres just such a decline in economic growth driven by the decline in independent inventors following the Great Depression. In this regard, this paper contributes to our understanding of how economic crises can affect the allocation of resources in the economy. Caballero et al. (1994) have formalized and extended a long argued point that recession could have positive effects by fostering "creative destruction" and therefore helping the reallocation of investment towards more productive use. In fact, even more generally than just "liquidationist-style" arguments, such crises could cause an overall shift in organizational form or in the incentives for existing inventors, which alter the impact of surviving patents (e.g. Gromb and Scharfstein 2002). Our evidence is consistent with these types of mechanisms. In fact, our results suggest that, while periods of severe and prolonged financial distress may cause declines in the quantity of patents filed by start-up like enterprises, innovation as a whole appear to be quite resilient. In contrast to prior research looking at large and established firms, we show a rise in allocative efficiency towards higher quality inventions and a shift in the organizational form of innovation production.

Our work contributes to the debate on the role that the disruptions to financial system played in instigating the Great Depression, and its consequences for economic outcomes. Economists have typically focused on effects of monetary policy (Friedman and Schwartz 1963; Richardson and Troost 2009; Gorton and Metrick 2013), demand declines (Temin 1976; Romer 1993), international flows (Eichengreen 1992), shocks to productivity (Cole Ohanian 2007), and bank lending amplifiers (Bernanke 1983; Gorton, Muir, and Laartis 2019). In many ways the Great Depression has been extensively used as a laboratory to examine the real effects of banking shocks (e.g., Ziebarth 2013) and we add another component to that discussion—the effects on innovation. The Great Depression represents one of the most severe financial crises in the history of the United States, with a third of US banks suspended and US gross domestic product falling by 26%. Recent empirical work has shown that bank failures had large negative effects on income growth (Calomiris and Mason, 2003), business revenues (Ziebarth, 2013), business failures (Babina, Garcia, Tate 2019), and employment (Ziebarth, 2013; Lee and Mezzanotti, 2015; Benmelech, Frydman, Papanikolaou 2019). As noted we find that there were also clear effects from local financial disruptions driven by the Great Depression on technological entrepreneurship causing shifts in organizational form. Unlike most of the prevailing literature though we also document a "bright side" to the Great Depression in the form of creative destruction. By receiving more citations, the remaining patents have higher long-run impact, significantly offsetting any decline on the extensive margin in patent filings. These findings complement recent work by Manso et al. (2019) suggesting some forms of creative destruction and exploitative innovation during economic downturns. Also, a broad literature shows that immigration (e.g., Kerr and Lincoln 2010, Moser Voena, Waldinger, 2014), taxation (e.g., Akcigit et al 2019), intellectual property laws (e.g., Moser 2005), and exposure to innovation (e.g., Bell et al 2019) can alter innovation, sometimes in surprising ways, and our findings on the dark and bright side of crises adds another important factor to consider in the drivers of innovation.

1 Historical and Institutional Background

1.1 The Organization of Innovation in the Early 20th Century

In the early 20th century, US innovation was in large part created within two main organizational forms: the R&D labs of established firms and independent inventors. While the boundaries between these two types of organizations may have been blurry in some dimensions, there are several aspects in which these two organizational forms differed substantially. First of all, the way they finance themselves was quite different. In general, independent inventors funded themselves in large part using their personal resources or raising equity financing from local wealthy individuals who played a role similar to modern angel investors (Lamoreaux et al. 2009; Nicholas 2010). In the quest for new financing, inventors were relying heavily on the connection they could obtain through local bankers and businessmen (Lamoreaux et al. 2006; Kenney 2011). Importantly, in this market financing was inherently linked to a specific project or business idea (Lamoreaux et al. 2006; Lamoreaux et al. 2009).

In contrast, the financing of innovation by established firms – similar to modern companies - was less dependent on the local networks on investors. While an exact quantification is difficult to achieve, it is generally accepted that a large part of the R&D investments were covered by internally generated cash flows (Hall and Lerner, 2010). At the same time, firms raised funding through a variety of mechanisms, such as the sale of equity securities (Nicholas 2008; Lamoreaux et al. 2009), issue of bonds (Jacoby and Saulnier 1947; Babina et al. 2017) or lending by banks (Nanda and Nicholas, 2014). These sources were generally used to fund more traditional corporate activities (e.g. working capital, tangible investment), but access to these markets - by affecting the general financial condition of a company - can have clear implications for innovation decisions.

The second key distinction between the two organizational forms was their business objectives and strategies. On the one hand, firms operating R&D labs were primarily interested in commercializing the technology directly, either by creating new products or integrating the new technology into the pre-existing portfolio. On the other hand, independent inventors did not generally have a pre-existing product base. For them, the development of a new technology was meant as either a step to raise financing and to start a business or monetize the technology through the sales of a patent or its licensing.

In this context, there are two important things to point out. First, while the financing of startups was in large part local, the markets for technology were already national (or at least regional) by the beginning of the 20th century (Lamoreaux et al. 2006, 2009). This dimension is going to have important implications for our empirical analysis. Second, in comparing independent inventors and firms we need to understand the dynamic connection between the two organizations. While not every independent inventor is aiming to establish a firm, some of them will eventually turn their organization into an established firm. One implication of this process is that patenting activity by independent inventors will always capture innovation happening outside traditional firms. However, we must recognize that our categorization is inherently imperfect, since we may categorize patenting made by early-stage enterprises as firms' activity, despite in practice this enterprise resembling more independent inventors than traditional, established firms.

When discussing independent inventors, it is important to highlight how this organizational form was quantitatively very important during the early part of the century. For instance, Nicholas (2010) show that in the 1920s 70% to 80% of all U.S. patents were attributed to independent inventors. At the same time, independent inventors were also important from a qualitative standpoint. Historically, some of the most impactful inventions were initially developed by independent inventors. Lamoreaux et al. (2009) and Nicholas (2010) find that over the 1900—1929 period, independent patents were, on average, higher quality than firm patents, as measured by future citations and the number of claims in the patent text. For example, Lamoreaux et al. (2009) show that a 33% of random sample of patents filed over 1928-1929 are cited by patents filed over 1975-2000 in the NBER patent data. This number is higher for independent patents (36% receive future citations) and lower among patents filed by firms with R&D labs

(25 to 30%).[4] This evidence is consistent with the results in Kelly et al. (2018), which shows that between 1930 and 1950 independent inventors represented a substantial share of breakthrough patents.[5] Our data - which covers almost the universe of patents during this period - also provides evidence consistent with this.

In light of these distinctions, there is a strong parallel between independent inventors in the early 20th century and technology entrepreneurs or start-up in modern days. From a financial standpoint, they both heavily rely on external early-stage local investors as a key source of financing, at least after an initial phase of self-financing and bootstrapping. In this regard, similar to the early 20th century, personal contacts and local investors' networks are still today key for the process of raising funds (Shane 2008; Bernstein et al. 2016; Gompers et al. 2019).[6] Moreover, the core investment thesis for both independent inventors in the 1920s and modern technological entrepreneurs is fairly similar: modern start-ups - similar to independent inventors - are focused on the development of a new technology with the objective of either selling the technology to an established company or raising financing to commercialize the product internally. Lastly, in both cases these organizations are an important engine for the development of new technologies.

Therefore, while it is undeniable that several aspects of the organization of innovation have dramatically changed over the past century, it is also the case that the key economic features through which both firms and technology entrepreneurs operate have remained surprisingly stable. This parallel implies that a study of independent inventors may provide insights that can be useful to understand the process of innovation today. Furthermore, this also suggests that measuring the activity of independent inventors at the local level could also proxy for the vitality of the local innovative environment. In modern data, the dynamism at local market has been usually examined by looking at the amount of economic activity that is undertaken in technology start-ups (e.g. Guzman and Stern, 2016) or young firms more broadly (e.g. Haltiwanger et al., 2012). In this period, a measure based on independent inventors may represent the best option, since this variable will actually capture the extent to which technology is developed outside

[4] Similarly, independent patents have on average of 35 claims, while patents by firms with R&D labs have 2 to 20 claims, depending on firm size.

[5] Technically, their paper only focuses on unassigned patents. As it will be clear in the data section, this definition is consistent with the one used in our paper to define independent inventors, but slightly more restrictive.

[6] In this regard, the key difference is that the financing of early stage enterprises today is relatively more institutionalized, because of the creation of organized angel groups (Kerr et al., 2011) and the growth of venture capital organizations (Ante, 2008; Kenney 2011).

firms. Furthermore, in this period employment in young firms in impossible to measure at granular level.[7]

1.2 Technology Entrepreneurs during the Great Depression

The Great Depression was the largest financial crisis in U.S. history, with almost a third of all banks suspended and a real GDP decline of 26% (Margo 1993; Richardson 2007). The concurrent disruption of banking activities and real economy growth were more than just coincident. At this time, financing was a more localized affair because of regulatory and technological constraints (Nestor 1992; Mitchener and Wheelock 2013). When banks failed, this caused massive disruptions in the ability of local firms to obtain financing. Several papers have shown that local bank distress during the Great Depression caused substantial declines in the growth of local non-financial firms (Ziebarth 2013; Hansen and Ziebarth, 2017; Lee and Mezzanotti 2017; Benmelech et al. 2017). This effect may result from the severing of valuable informed lending relationships (Petersen and Rajan 1994) or from local general equilibrium feedback mechanisms caused by a deterioration in lender (Bernanke 1983) or borrower (Bernanke and Gertler 1989) balance sheets.

Therefore, while the impact of the Depression on traditional businesses is well-established, much less is known about how this affect the activity of independent innovations, and entrepreneurship more generally. To start examining this issue, we plot in Figure 1 the number of patents by independent and firm inventors in the first half of the 20th century. This figure shows that, while independent inventors accounted for the majority of patenting in the 1920s, this changed quickly around the Great Depression. In particular, the number of patents filled by independent inventors felt by almost 50% during the years of the Depression. As a result, patents by independent inventors were surpassed by patents filled by companies. Importantly, this shift was permanent, as ever since independent inventors were unable to recover the gap from firms. These conclusions, which use all US patents, corroborate the findings by Nicholas (2010) using a sub-sample of US patents.

Clearly, there could be several explanations for these trends. One commonly held view is that this shift reflects a change in the nature of technologies developed during this period (Teece David 1988; Hughes 2004; Lamoreaux and Sokoloff 2005). In particular, as the process of developing and using technologies became more capital intensive and complex, firms became a relatively more efficient organizational form

[7] Indeed, using more recent data for which both time series are available for the same period we find that a sizable correlation (0.5) between county-specific fraction of patents produced by independent inventors and employment in 0-3 year old firms.

that independent inventors. For this argument to hold, the standard assumption is that firms—for both institutional and economic reasons—are in a better position to finance large quantity of investments over a long periods of time.

However, this simple hypothesis appears to fail to explain the full dynamics of the contraction in independent inventors' patenting during this period. For instance, Figure 2 shows that the decline in independent patenting happened within virtually all major technology classes around the Great Depression. Since it is not likely that technological shocks will occur across all industries nearly simultaneously (and concurrently with the Great Depression), an explanation that is only technology-based will likely fall short to rationalize the large contraction in independent patenting. Clearly, we are not claiming that technology considerations were not important to understand the decline. Instead, we are simply highlighting how a more complete theory requires something else to understand the sudden decline in independent inventors during this period.

In this context, another view is that the Great Depression contributed to the demise of independent inventors and their startups. In particular, several economic historians have suggested that the shocks to local financing brought about by the Depression led to disruption of local investors' networks and to a reduction in the willingness to supply angel financing. For example, Kenney (2011) writes that "the obstacle to establishing these new firms was a shortage of risk capital, which they believed was due to the changes caused by the Depression that discouraged wealthy individuals from risking their capital in untested firms."[8] In addition, Lamoreaux et al. (2009) concludes that "the subsequent dominance of large firms seems to have been propelled by a differential access to capital during the Great Depression."

Importantly, these two explanations are not necessarily orthogonal to each other. While we believe that technology alone cannot explain the sudden decline in independent inventors around this period, this force could very well play an important role in explaining the persistence of the decline and the speed of transition between the two organizational forms. Therefore, our tests will simply examine how the financial disruption brought about by the Great Depression was a catalyst for the decline in the activity of technology entrepreneurs, keeping constant the overall trends in technology. However, this potential contemporaneous shift in technology is clearly an important factor when considering the external validity

[8]Other examples are Landes et al. (2012): "Many firms [of the 1930s] run by inventor-entrepreneurs were either acquired or driven out of business" and Wall Street Journal editorial on January 24th, 1938: "there is no 'venture capital' to speak of [in the U.S. economy] because there is no venture spirit on the part of capital owners or those who normally would be borrowers of that capital."

of our study.

1.3 Bank Distress and Technology Entrepreneurs

While the notion that bank distress could dramatically affect the innovative process is intuitive, the exact mechanism through which this phenomenon could take place is more ambiguous. As discussed before, previous research has already established that bank distress did have a large impact on firms' activity during this period. However, most of these papers assume that banks' distress affect the economy through a contraction in lending (bank lending channel). In general, this explanation is likely to be unsatisfactory in this setting, since innovation activity is not generally funded through bank credit channel. One exception may be the innovation activity that was undertaken within established firms. These entities commonly raise financing for investment or working capital purposes through banks. As a result, a shock to lending in these cases may spill over from more traditional business activities to R&D. Consistent with this narrative, Nanda and Nicholas (2014) find that exposure to bank failure negatively affected firms with R&D labs, albeit these effects are mostly concentrated in industries more dependent on external finance.[9]

However, distress in the banking sector may still affect the funding of technology entrepreneurs different ways. One hypothesis is a distress-driven decline in demand: as local firms suffer because of the contraction in lending, the demand for technologies developed locally may decline. In general, we think that this demand explanation will fall short in explaining our results: as we mentioned earlier, the market for technologies at the time was already quite developed and demand was in large part national or regional (Lamoreaux et al. 2006, 2009). However, in our empirical analysis we will discuss more extensively the role of demand factors and provide more evidence in rejecting this hypothesis.

Alternatively, we hypothesize that bank distress could impair the supply of funding coming from wealthy individual acting like "angel investors" in the local market. This disruption of the local "angel financing" could happen for several reasons. First, banks, especially local state banks, were known to be central nodes of information transmission between local inventors that needed financing and wealthy individuals, such as bank clients, local businessmen, land owners and banks' officers and directors themselves, who were willing to back the inventors (Lamoreaux et al., 2006). Hence, failure of local banks can

[9]The concentration of the effect in industries that are actually more dependent on external finance may help rationalize this result with Mowery and Rosenberg (1989), that document that firm investments in R&D facilities and personnel actually rose during the Depression.

sever information flows and destroy relationship capital, which are important pieces of the local innovation ecosystem. This effect in principle could affect any type of organization, but it should have a larger impact on independent inventors, since this type of organization has fewer financing alternatives, receives financing on a project-by-project basis, and is more dependent on the local networks to secure financing.

Second, local bank distress would likely reduce the ability or willingness of local wealthy individuals to invest directly in new technology ventures. In many cases, the financial-backers of technology entrepreneurs were business owners of other companies in the area (e.g. Lamoreaux et al., 2006). Since bank distress negatively impaired traditional businesses, it is reasonable to think that this would also have an impact on the portfolio allocation of these business owners. Third, bank distress - by effectively impairing the functioning of the local economy - could also affect innovation indirectly. For instance, counties where banks failed may experience a reduction in human capital as well as a deterioration in infrastructure.

While our ability to identify the specific channels of transmission will be somehow limited, our analysis will try to shed light on the connection between the decline in technology entrepreneur and the health of the banking sector during the Depression. Despite the limitations, we are going to be able to disentangle the effect of bank distress as a shock to the supply of financing from the effect that the Depression may have had on the demand for technology. At the same time, we are going to provide suggestive evidence on the channels. Lastly, in the last part of the paper, we are going to use this framework to shed some light on the overall impact of the shock on the innovation ecosystem.

Overall, we think these tests are important for several reasons. First, from an historical standpoint, the documented shift of innovation into firms represents one of the largest changes in the organization of innovation in the US history. Therefore, understanding better the causes and consequences of this change is important on itself. Moreover, while there are many papers that study how the Great Depression affected established firms, to our knowledge, there are no studies that focus specifically on more entrepreneurial innovative forms. Second, the setting represents an important laboratory to study how disruptions caused by large financial crises affect the innovation ecosystem, the allocation of innovation across different organizational forms, and the economic significance of that potential shift for the impact of innovation. In large part, research in innovation has generally focused on technology entrepreneurs and firms as separate parts of the innovation ecosystem. Our paper is one of the first that tries to examine how shocks may not only affect the two areas separately, but whether they also may lead to reallocation across the two. Third, this analysis can also provide direct evidence on the effect of large financial shock on overall dynamism.

To answer these questions, an historical context can be particularly useful. First, the long time series of the patent data allow us to measure the impact of the shock over a long time period. This feature is quite important to understand whether these shocks have important economic effects in terms of the impactfulness of innovation. As we discussed earlier, a third of patents filed in 1928–1929 are still cited 50 to 70 years later (Lamoreaux et al. 2009). Second, innovation activity was more widespread across the country at the time. As a result, our identification strategy can exploit variation across locations to empirically identify the effect of the crisis. The same would be more difficult to do today, as innovation is more concentrated in coastal, urban areas. Third, the availability of complete count census data through 1940 allow us to build longitudinal inventor data from 1910 though 1940 that provides us micro-level data to test different mechanisms. These rich data are not available in modern data.

2 Data

2.1 Measure of Innovation

We collect data on the universe of United States Patent Office (USPTO)-approved patents, representing over 9 million patents from 1830-–2018, which include filing and grant date, inventor's name, assignee's name (if assigned), and their locations. For patens granted in 1910—2018, we also have information on future patents that cite these patents as well as the patents' technology classification (e.g. electricity) coming from the USPTO's Cooperative Patent Classification (CPC). We follow closely the methodology developed by Berkes (2016) to construct the patent and patent citations data. For convenience, we briefly describe the data collection process in Appendix.

We separate patents in four groups: independent patents, U.S. firm patents, foreign patents, and patents with missing information on the location of inventor and assignee, if assigned. Figure 8 shows an example of an independent patent—the famous light-bulb invention by Thomas Edison, who in 1880 founded "Edison Electric Light Company" to market his hew invention. The independent inventors' patents are usually either unassigned, assigned to the inventor, or assigned to other individuals (e.g., angel investors). Thus, we define independent patents as those granted to inventors residing in the U.S.

that were either unassigned or assigned to individuals at the time of the patent grant date. Figure 7 shows an example of a patent assigned to a U.S. firm (i.e., General Electric) at the time of the patent grant. Patents assigned to firms are usually produced by inventors employed within large firms with in-house R&D labs who would have been contractually obliged to assign their inventions to their employers (Lamoreaux and Sokoloff 2001b; Lamoreaux et al. 2009; Nicholas 2010). Thus, we define U.S. firm patents as those that were assigned to a U.S. company at the time of the patent grant date.

As described above, the financial markets for funding startup-like innovations were highly localized, and hence a county-level geography roughly identifies the physical proximity of innovator and local investors. We match county-level information to inventors' city-state locations. We are able to match 99% of patents with city-state information. We then create a five- or ten-year panel of counties that have at least one patent in our data and then aggregate patents at each county-period for all U.S. patents (variable "TotPat"), independent U.S. patents (variable "IndPat"), and U.S. firm patents (variable "FirmPat"). For all three patent categories, we calculate county-level measures of number of patents, number of future citations citing those patents, and average number of futture citations measured as total citations over number of patents When a county-period does not have a patent, we set the patent count to zero.

2.2 Bank Distress

Our measure of bank distress follows much of the literature (Calomiris and Mason 2003; Nanda and Nicholas 2014) in using Federal Deposit Insurance Corporation (FDIC) county-level annual reports on active and suspended banks and their deposits from 1920-1936. These data are unavailable in the states of Wyoming, Hawaii, and Alaska, and in the District of Columbia, and do not distinguish bank failures from bank suspensions. However, Calomiris and Mason (2003) argue that these shortcomings do not interfere with identifying bank distress empirically. We use 1930 as the starting year for our banking sector distress indicator since it wasn't until at least 1930 that banks began to fail in serious numbers, destroying relationship capital and access to finance (Bernanke 1983; Calomiris and Mason 2003; Nanda and Nicholas 2014). Suspensions and failures of banks from 1930 through 1933 proxy for the disruption to the local financial ecosystem. We indicate that a county is in distress during the Great Depression if there is at least one bank suspended in that county from 1930-1933, which represents 71% of all counties. This provides a relatively simple intuition for interpretation of any observed treatment effects and is our primary measure of distress throughout the paper. Given how many counties experience distress, we also consider two additional measures of bank distress. First, we use a continuous measure of the percent of all deposits suspended in a given county over 1930-1933. Second, we use a dummy equal one for counties with the above median deposit suspensions.. We match bank distress data to the county-level panel data using inventor's county location.

Table 1 presents summary statistics on the county-level patent measures for aggregates for the 1920s and on other county-level measures used in the analysis.

2.3 Complete Count U.S. Census

Using complete count U.S. censuses of 1910, 1920, 1930, 1940, we can match 70% of U.S. inventors (~500k people) on patents filed over 1905–1944, which allow us to get detailed demographic, geographic, and socio-economic data at an individual level and create a longitudinal sample of inventors across four decades. We use longitudinal inventor data to examine mechanisms.

3 Results

3.1 Setting

The key objective of this section is to identify the impact of the disruption to local financing caused by the Great Depression on innovation activity. To examine this question, we use a differences-in-differences specification which compares innovation activity across counties that were differentially affected by bank distress during the Depression period. To remove the effect of regional business cycles and changes in state-level regulation, all our specifications will also contain state-by-time fixed effects. We also include county-fixed effects to control for time-invariant differences in innovation across counties. This approach relies on the assumption that, within a state, the key difference in economic conditions across counties with different level of distress is the ability to access financing during the Depression.

We quantify innovation across locations using patent measures. In particular, our analysis focuses specifically on patenting activity by independent inventors, but we will also examine the effects on aggregate activity and firms' patenting later in the paper. We initially examine the short- and medium-run impact of the shock, in particular looking at the periods 1920-1930. Altogether, our primary specification is:

$$Ln(Innovation)_{cst} = \alpha_c + \gamma_{st} + \beta\, BankDistress_{cs} \times After1929_t + X^{'}_{cst}\zeta + \epsilon_{cst} \quad (1)$$

where c denotes a county, s – a state, and t – time (defined in decades). $Ln(Innovation)_{cst}$ is the natural logarithm of either number of patents, total future patent citations, or average citations per patent[10] α_c is county fixed effects; γ_{st} is state-time fixed effects; $BankDistress_{cs}$ denotes the degree of bank distress in county c in state s during the Great Depression and equals 1 if the county had at least one bank suspended over 1930–1933, and 0 otherwise; $After1929_t$ equals 1 for observations starting in 1930, and 0 otherwise. X_{cst} will include county-specific controls, that are usually measured before the time of the Great Depression and interacted with post-dummy. Our main results will use decennial data, but we will also consider five-year windows when estimating the dynamic model. The estimate of the effect of local bank distress on innovation is given by β, which measures differences in patenting in counties with higher bank distress compared to counties with lower bank distress. We cluster standard errors by county which is the level of our treatment (Bertrand et al., 2004).

In interpreting these analyses, we need to provide convincing evidence that our tests really captures the negative effects of bank failure on local innovation, rather than other spurious economic forces that are unrelated to bank distress. The presence of a spurious relationship between these variables could be explained by reverse causality. In this case, it could be that the weakness of the innovative sector led to bank failure, and not vice-versa. To understand whether this is a valid concern, it is important to understand why banks entered in distress during the Depression. To the extent that failures were driven by panics rather than weakness in the fundamentals (e.g. Friedman and Schwartz, 1963), then reverse causality should not be a concern. However, if distress is driven by a deterioration of the demand for credit, then reverse causality could be a more serious concern. In general, there is some consensus that the demand channel is not able to explain a large part of the contraction. For instance, Calomiris and Mason (2003) find that lagged liabilities of failed companies does not explain bank failures. This hypothesis is likely to be even less plausible for the innovative sector, which had minimal exposure to banks' loans. In this context, Nanda and Nicholas (2014) show that publicly traded R&D firms – which are likely the R&D firms with higher share of assets funded by bank loans – only accounted for a minimal share of banks' outstanding loans. Overall, reverse causality does not appear to be a key concern in this

[10] We add one to the number of patents before taking logs in order to avoid issues with counties without any patents over a given period as is standard practice.

context. However, some of our robustness test will also provide further evidence against this concern.

Alternatively, a spurious relation between bank distress and innovation could be explained by the presence of an omitted variable bias. This is a serious concern in this analysis since areas that were characterized by bank distress were clearly not randomly assigned. To visualize this fact, in the first panel of Figure 3 we plot the estimated differences in county-level characteristics between areas that experienced bank distress during the Depression to areas where there was no failure. This analysis is conducted adjusting for state differences.[11] On average, we find that counties experiencing bank distress are significantly different than areas that did not experience bank failures. For instance, our treated areas tend to produce more patenting (looking at both total and independent patenting) in the 1920s and they also had more banks. Not surprisingly, these areas that experienced bank distress also end up with higher unemployment in 1937 and they were also more exposed to the agricultural boom in 1917-1920, which is generally considered one of the sources of weakness for the banking sector before the Depression (Rajan and Ramcharan (2015)). However, most of these differences between treatment and control are really explained by the fact that counties experiencing distressed are on average larger than counties that did not experience distress. Consistent with this hypothesis, in the second panel of Figure 3, we repeat the same analysis as before now also controlling for the log of population in the county in 1920. Strikingly, this extra control absorbs a large part of the variation along the treatment. For instance, controlling for population we do not find any significant difference in the amount of independent innovation produced in the county in the pre-period. This result highlights the importance of adjusting for cross-sectional differences - in particular county size - when running our analyses.

Despite this result, the risk that omitted variable biases may drive our results is still relevant in this case. While it will not be possible to present one single test that can rule out this hypothesis, the battery of analyses that we present in the next section will help us to assuage any concern on this dimension. After providing convincing evidence of the relationship between bank distress and innovation, we will analyze the mechanism through which bank distress affected innovation. While it will be hard to pin down a specific channel, we will provide some evidence that is consistent with the importance of local banks in the local entrepreneurial environment.

[11] The analysis reports the beta and 95% confidence interval for coefficients that are estimated running a simple regression of the outcome reported - which is z-scored to make it more comparable across variables - on a dummy for counties with bank distress controlling for state fixed-effects.

3.2 Main result and robustness

In Table 2, we show initial evidence that county-level variation in exposure to the financial crisis, proxied by bank suspensions, is associated with a reduction in the quantity of total inventor patenting. In particular, our estimates suggest that counties that experienced bank distress saw a drop in independent patenting between 1930 and 1920 that was 13% higher than counties in the same state without bank distress. This effect does not depend on the way we measure bank distress. Indeed, in Table (A.1) we show that the same results also hold using alternative measures. For instance, the effects are consistent when splitting the sample at the median of distress - measured as share of deposits at suspended banks - or when we simply use the continuous measure. Taking this result at face value, it suggest that the financing distress connected with the Depression had a significant impact on the activity of technology entrepreneurs.

However, before we can interpret the results in this direction, we need to provide more evidence that can help us to rule out the confounding factors discussed before. To start, we examine the dynamic of the effects using a longer panel (1900-1950) organized over five-year windows. If our results are explained by an omitted variable that is unrelated to bank distress, we should expect to find our result also before the Depression. In other words, we should find that high distress counties were already experiencing different trends in innovation activities before the shock. This would be the case if, for instance, areas with high bank distress during the Depression are regions with declining economic activity. Figure 4 provides evidence that is inconsistent with this concern. In general, we find that until 1930s counties that experienced distressed during the Depression did not differ in their relative trends in independent inventors' activity. This changed sharply during the period 1930-1934. At this point, we document a reduction in innovation activity by technology entrepreneurs in affected areas.

Given the lack of differential trends, the main remaining concern for our analysis is that bank distress at county level may be correlated with some other shock that was contemporaneous to the Depression but unrelated to the contraction in funding. One hypothesis is that bank distress captures heterogeneity in demand for technologies across counties, which in turn may affect the production of technologies in the area. To the extent that this shift in demand happens roughly at the same time as the Depression or as a result of it, its effect may be undetectable in the pre-trend analysis. Regarding this concern, there are a few important things to consider. First, from a theoretical standpoint, a demand-side explanation would require that, in some way, the decision of an inventor to develop a technology is influenced by the demand for that technology in the local area. However, this hypothesis goes against a large body of work in economic history (e.g., Lamoreaux and Sokoloff 2001b), which has shown that the market for technology during this period was either national or - at the very least -regional. Therefore, variation in demand should not be captured in our analysis, in particular as we include state fixed-effects.

Second, to the extent that firms and technology entrepreneurs produce a similar type of innovation, a demand explanation would also predict a decline in firm innovation in distress areas. However, as we show in Table 2 and discuss more formally later in the paper, we find that bank distress does not seem to predict any change in aggregate patenting by firms at county level. This firm-level result helps more broadly to address other alternative explanations, which would generally predict a similar response between firm and independent inventors. For instance, one special case is the reverse causality hypothesis discussed earlier. If the decline in banks was caused by the reduction in innovation and not vice-versa, the contraction should be observed also in firms. If anything, the effect on firms should actually be larger, since banks and firms are more likely to be connected through direct lending relationship.

These arguments suggest that demand-side explanations are unlikely explanations for our results. However, we can also provide direct evidence against this hypothesis. In general, if we think that a demand shock explains our results, we should also expect to find this result for technologies in which local demand is likely to be more important. Despite the claim that the market for technology was mostly national, it may still be plausible that certain technologies are more sensitive to local demand than others. To examine this issue, in Table 4 we reshape our data at county-time-technology level, where the technology is based on the large CPC technology classes.[12] Since it is hard to categorize ex-ante which technology is more likely to be affected by local demand, we take two approaches that do not require any ex-ante categorization. To start, we augment our main specification using technology by time fixed effect. To the extent that demand explains our results and this is heterogeneous across technology, we should expect our main effect to go away. Instead, we find that the result with this new set of fixed-effect is still large and significant (column 2), and it is actually even larger than the one we would obtain by running our baseline result on this reshaped data (column 1). On top of this, we repeat the main specification separately for each technology. Across all of them, we still find sizable and significant results. Across the

[12]In particular these groups are human necessities, performing operations or transporting, fixed constructions, mechanical engineering, lighting, heating, weapons, blasting engines or pumps, and physics.

five groups (columns 3 to 7) the magnitude is always close to the average effect (column 1).

At the same time, the main effect does not also appear to be completely explained by other characteristics of the county interacted with the timing of the Great Depression (Table 3). In particular, our previous discussion highlights the importance of adjusting for differences in size across treatment and control. In column 1, we can show that our main result goes through once we also control for the size of population in 1920 interacted with a post-dummy. The same also happens when we control for a measure of the size of the banking sector at county (column 2).

In the next two columns, we control for two variables that should also capture the negative effect of the Great Depression. In particular, we control for the change in sales at county level between 1929-1933 in column 3 and the unemployment rate in 1937 in column 4.[13] The logic behind this test is simple: an omitted variable would be a concern only if this variable is correlated with the level of bank distress in the local area. In general, the same factors that may have been correlated with one dimension of the Great Depression - bank failure - may be also correlated with other dimensions, like the contraction in retail sales or the unemployment rate. Therefore, controlling for these alternative proxy for the depth of the Depression can help to gauge the extent to which our result may be capturing other economic forces that we have been unable to control in our main analysis. However, it is also important to keep in mind that these variables are also endogenous to bank distress, and therefore may partially capture the impact of bank failure. In general, we find that the addition of these controls do not significantly affect our estimates, therefore providing reassuring evidence for our analysis. Furthermore, the same result also holds when we add all the controls together(column 5).

As an alternative way to deal with the heterogeneity between treatment and control, we also implement a matching estimator using nearest neighbor matching approach. In particular, we start by considering all the counties that did not experience distress during the Depression. For each of these counties, we check whether we can find any other county that experienced bank distress, where the following condition also holds: (a) the county is in the same state; (b) population is within a 25% bandwidth around the unaffected county; (c) independent inventors' innovation in the pre-period (1920) is similar.[14] In the end, we use for the analyses only counties that are selected using this criterion. As a result, the sample

[13] We use 1937 because county-level unemployment data was not available between 1929-1933.

[14] We divide counties in three groups: (a) no independent innovation (zero patents before); (b) moderate independent innovation (between zero and fifty patents; (c) high independent innovation (above fifty patents). We then use this definition to match firms.

of counties examine is only about a third of the original sample, but on average the firms in treatment and control are much more homogeneous. In Table A.2, we re-estimate our main specification using this matched sample (column 1 and 2). Overall, we are able to replicate our main finding, in terms of both economic and statistical significance.

3.3 Bank Distress and Independent Inventors

Altogether, these tests support the interpretation of our results as evidence of the importance of bank distress in explaining the decline in independent inventors. Before moving forward, we want to present two extra results that are consistent with this interpretation and allow us to further bolster the connection between the shock, the supply of local financing, and the innovation activity of independent inventors.

First, we can show that the drop in independent inventors can be identified also using a different proxy for the weakness of financing. In particular, we identify counties with weaker banks at the time of the Depression using heterogeneity in the exposure to the 1920 farming crisis, as discussed in Rajan and Ramcharan (2015). In this paper, the authors argue that the boom in the agricultural sector in the late 1910s - which was in part a consequence of the increase in food demand during WWII - represented an important factor to understand the weakness of US banks at the beginning of the Depression. The idea is that the boom period caused an increase in farms' leverage. As prices declined in the 1920s, this increase in leverage translated into an increase in mortgage default, which consequently weakened the balance sheet of banks.

Following this paper, we construct a measure of exposure to the farming shock by looking at the increase in revenue that is induced by the changes in price in the global commodity markets.[15] To start, we can show that indeed counties that experienced a larger farming boom during the 1917-1920 also experienced higher bank distress during the Depression (in column 1 of Table **??**). This confirms that this approach still captures weakness of the banking sector during the Depression. However, relative to our main measure, this is also predetermined with respect to the shock itself. In Table **??**, we replicate the same difference-in-difference model presented before using this alternative treatment. Columns 2 and 3 show results that are consistent with the results using bank distress: an increase in the boom in farm land caused by the WWII is linked to a reduction of independent inventors activity after the beginning

[15] To be specific, our treatment is the county-level change from 1917 to 1920 in the international commodity price index calculated for each county, where weights are the crop share of a given farm product out of total county farm output and prices are international farm product prices.

of the Depression.

3.4 The Effects over the Long-run

The evidence presented so far has confirmed that bank distress during the Great Depression had a significant impact in explaining the contraction in patenting activity by independent inventors. Before moving forward, it is important to understand to what extent this effect was temporary or persistent. This question is particularly important given the context of these results. As we have shown before, the aggregate decline in independent inventors was not a transient phenomenon. While our results confirm that the shock caused by the Depression was a significant factor in triggering this decline, this does not necessarily imply that the effect of our main shock persisted in the long-run.

To examine this issue, we are going to repeat our main analyses using a sample that covers patenting activity by independent inventors up to 1990. One important caveat in this type of analysis is that we are not going to be able to prove that the Depression caused a long-term decline in independent patenting. Instead, we can simply make a statement on whether the short-term effects of the banking shock persisted over time. The two things are related but they are not necessarily equivalent.[16] Despite this limitation, which is common in this type of studies, understanding how our results persisted is still important, since it may help clarifying how the effect of the Depressions may still explain a large share of changes in the innovation ecosystem years after the end of these events.

With this limitation in mind, we then examine the data. In the pre-trend analysis (Figure 4), we have already shown that the contraction in independent inventors' patenting did not simply characterized the 1930s, and evidence of a reduction in patenting in the affected areas was also present in the 1940s. In Table 6, we extend this analysis further. In particular, using data at decade level as in the previous analyses, we separately estimate a parameter of bank distress for the period 1929-1939 and post-1939. The estimates suggest that counties that experienced bank distress during the Great Depression still appear to be characterized by lower patenting by independent inventors after the 1939. The effect is about 30% smaller than the effect in the 1930s, but still sizable and significant. In particular, relative to the pre-Depression level, counties that experienced bank distress were still characterized by 9% lower independent patenting between 1940-1990 than the non-distress counties in the same states. This evidence

[16] For instance, it is possible that the government targets explicitly areas that were characterized by bank distress. As a result, this intervention - which is correlated with our shock - will affect our estimates.

suggests that the negative effects of bank distress were still visible also more than a decade after the end of the Depression.

4 The Great Depression and the Innovation Ecosystem

4.1 Discussion

So far, we have shown that the Great Depressions was followed by a contraction of innovation by independent inventors. Importantly, these effects are persistent over time. There are several ways to interpret this evidence. On the one hand, at face value this result may be consistent with the idea that the financial contraction brought about by the Depression negatively affected the level of dynamism in the economy. In fact, our tests show that the financing contraction led to a sizable reduction in innovation activity that is undertaken outside the firm. In turn, this may suggest the presence of a "missing generation" of highly productive entrants (Gourio et al. 2016).

However, on the other hand, a reduction in the amount of innovation that is undertaken by technology entrepreneurs do not necessarily imply a reduction in the overall dynamism of the economy. First, the long-run implications of the shock do not only depend on its quantity effect, but also on the quality adjustment that this may generate. As discussed by Caballero et al. (1994), a negative shock may also represent an economic opportunity to the extent that this event also triggers a cleansing dynamic in the economy. Second, the actual impact of the shock for the economy also depends on the ability of innovation to shift across different types of organizations. Altogether, a crisis period may be also an opportunity to reshape innovation efforts towards more efficient organizational forms and impactful projects (Manso et al. 2019).

In order to explore these dimensions, we increase the breadth of our analysis by expanding our investigation to the overall ecosystem of innovation at local level. In particular, we present three set of tests that can help clarifying our initial results. First, we test whether the decline in quantity of innovation was also accompanied by a decrease in the overall quality of independent innovation, as measured by total and average future citations. This may be particularly interesting in this case, since one of the benefits of the historical context is that the quality of patents filed can be evaluated based on the long-run influence that patents have on citations. Second, we examine whether the drop in quantity of independent innovation also led to a decrease in overall local innovation activity, looking also at the role played by firms during this period. To explore this second question, we also rely on rich patent data that allows us to measure local inventions not done by independent inventors—inventions done by firms—and the aggregate patenting by firms and independents. Moreover, we build a matched data set at the individual-level between the U.S. censuses surrounding the Great Depression and our inventor data. This allows us to examine individual inventor migration across organizational forms of innovation. Third, we examine whether the shock led to a reduction in the stock of human capital in the area. Also in this case, we will take advantage of our mapping with the U.S. censuses.

4.2 Analyses

First, we look at changes in quality of innovation. In Table 7 we study this dimension using the same differences-in-differences design but looking at total citations received as outcome. In stark contrast to quantity results, we find essentially no differential change in future citations for independent inventors in more distressed counties. We can also see this in Figure 5 which replicates the design of Figure 4, but looking at this alternative outcome. Just like in the prior figure, we find no evidence of pre-trends, but - unlike before - we also do not find any change in behavior after the shock.

How do we reconcile these seemingly disparate findings on quality and quantity of innovation? In Table 8 and Figure 6 we show that the divergent results are driven by a change in the average patent quality. The average citations per independent patent rises suddenly in counties that experience more severe economic distress, despite no evidence of differential trend prior the Depression.[17] This evidence - combined with the decline in the quantity of innovation - seems to suggest that the drop in activity by independent inventors is in large part driven by lower quality projects that are dropped. Therefore, while technology entrepreneurs were forced to reduce their activity in response to the shock, inventors with high quality technologies were still able to succeed in the marketplace.

Second, we find that in contrast to technology entrepreneurs, the aggregate local innovation activity by firms did not seem to be impaired, as shown in Table 2. If anything, patenting by firms seems to actually increase relatively more in distressed areas over the longer-run, as shown in Table 6. Despite

[17]These findings stand in contrast to those found for more externally finance dependent firms in Nanda and Nicholas (2014). In their paper, they find a substantial reduction in the quantity and quality of patents, and suggests more than just financial constraints may be driving the observed responses of independent inventors. So while financing constraints may play some role in our setting, the dramatic decline in independent patents, relative to even the largest reductions seen among groups of incumbent firms, and the rise in patent quality, suggests that other mechanisms of more importance for start-ups, such as local equity capital, risk aversion, employment opportunities, and migration, may also be important contributors (Haltiwanger et al. (2012); Adelino et al. (2017)).

the limitation of analyses that look at longer-term response, this evidence may suggest that there may be some substitution in the production of innovation between independent inventors and firms.

To try to explore this hypothesis, we turn on individual inventors' data and test whether we find any shift in the incentive of independent inventors to start working for firms in the post-Depression period. In order to run this test, we restrict ourselves to the subset of inventors who can be found in the 1920 Census, patent as independents prior to the Great Depression (1910-1920) and have at least one patent during the 1930.[18] Using this cross-section, we then test whether within a state independent inventors were more likely to shift into firms in counties that experienced high bank distress.[19] The idea is to understand the extent to which financial distress caused by the Depression led a reallocation of inventors into firms, as the long-term positive effect on firm patenting may suggest. As we show in Table 9, independent inventors operating in high distressed areas were more likely to move into firms in the following decade, and this holds both without any control but also adding county level (column 2) and individual level (controls).

To bolster the interpretation of this result, in Table A.4 we conduct a placebo analysis looking at whether also before 1930s we had independent inventors moving into firms more in our highly affected counties. In particular, in columns 1 and 2 we examine a sample of independent inventors that were active in the 1910s and check whether they were more likely to move into firms in the 1920s if they were in counties that experienced more distress during the Great Depression, and in columns 3 and 4 we repeat the same analysis looking at 1900s inventors moving into firms in 1910s. Across all these analyses, we consistently find no evidence of a different likelihood to move into a firm prior to 1930s.

This cross-organizational migration is consistent with more muted response for county-level firm patents, if innovative workers are re-allocated from more to less externally finance dependent firms in counties with more severe bank distress. Going back to our original county-level data, we show in Table **??** long-run reductions in independent patenting in these distressed counties—the reductions that last till the present day. By contrast, firm patenting in distressed counties appears to see a resurgence in the long-run, fully compensating for the long-run decline in independent patenting. This would again be consistent with migrations across organizational forms, some of which are faster and some slower

[18] To assign the location during the Depression we use the location in 1930 Census and, when this is not available, the location in the 1920 Census.

[19] For this analysis, we use the continuous measure of bank distress as our main treatment. The reason is that the previous treatment version (bank distress equal to one when there is some distress event) does not have enough variation using individual level data, as more than 90% of the sample resides in an affected area. In Table A.3, we show the version of the result using the bank distress employed before (null effect). In columns 3 and 4, we also show that using a dummy constructed at the median of the sample distribution provides consistent result to the continous measure of distress.

moving. Overall, the movement of inventors across organizational forms might explain why the aggregate county-level firm patenting appears to have been fairly insulated from bank distress, despite the declines observed for some large firms with R&D labs in Nanda and Nicholas (2014).

One remaining concern is that the shock may have affected the local economy in part because of a reduction in the quality of human capital. This would have been the case if inventors have responded to the shock by moving outside the county. Since independent inventors were likely to be more fragile to the local shock than firms, this mechanism may have affected independent inventors more. Indeed, the recent literature in economic history highlights the importance of migration to understand the effect of the Depression in the American economy (Feigenbaum 2015). In Table 10 we show that data are not consistent with this hypothesis. In particular, using the longitudinally matched inventor data, we find no evidence that inventors actually were more keen to migrate out of highly distressed areas. This fact is true both for inventors working for firms or independently. This result suggests even more that the shock—while it affected the way innovation was organized—did not significantly impact the stock of human capital in the area.

5 Conclusion

Using a differences-in-differences design comparing counties with different level of bank distress between 1929 and 1933, we document the important role of the Great Depression in triggering a massive reduction in the quantity of patents filed by the largest innovators of that period—independent inventors. Since independent inventors in large parts capture a class of technology entrepreneurs, at face value these results seem to suggest that the Depression led to a large reduction in dynamism in the economy.

However, this interpretation appears at odds with other results. First, despite the decline in the quantity of innovation, the average quality of patents filed by independent inventors rose dramatically. Second, the shock in itself did not affect firms negatively. If anything, firms seem to have benefited in the long-run, in part because of a reallocation of inventors into firms. Third, the shock does not seem to reduce the amount of human capital in the area, as inventors do not leave the affected regions in response to the shock.

This evidence on the Great Depression can be thought as a cautionary tale on the importance of examining the impact of shocks to innovation activity by looking at the overall innovation ecosystem.

In general, sufficiently large shocks to financing—on top of having a direct effect on one group of innovators—can also lead to a reallocation across more and less affected organizational forms. At the same time, to the extent that the shock actually induces a cleansing effect (Caballero et al., 1994), the overall effect on technological progress could be substantially lower.

These results are particularly useful in the context of the contemporaneous debate regarding a reduction in dynamism in the economy. For instance, these results are consistent with Guzman and Stern (2016), that have highlighted the importance of adjusting for the quality of start-up in order to study dynamism. Clearly, our results, which cover a very different historical period , cannot directly speak to whether dynamism declined or not today and in particular after the Great Recession. However, the main intuition from the paper will also apply to modern economies.

Furthermore, this paper also provides novel evidence that can help understanding the large shift in the organization of innovation that characterized the US economy between 1920 and 1930. In particular, our findings suggest that the relative increase in firm relative to independent innovation does not only reflect a technological change, but it is also explained by the negative effect of the Great Depression.

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Figure 1: Aggregate Number of Patents by Patent Type

The figure shows an annual number of patents by patent type. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO). Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. U.S. Firm are patents that were assigned to a U.S. company at the time of the patent grant date. Non-U.S. are patents by non-U.S. inventors or patents assigned to non-U.S. entities. No Information refers to patents that have missing information on the location of the inventor and assignee if assigned.

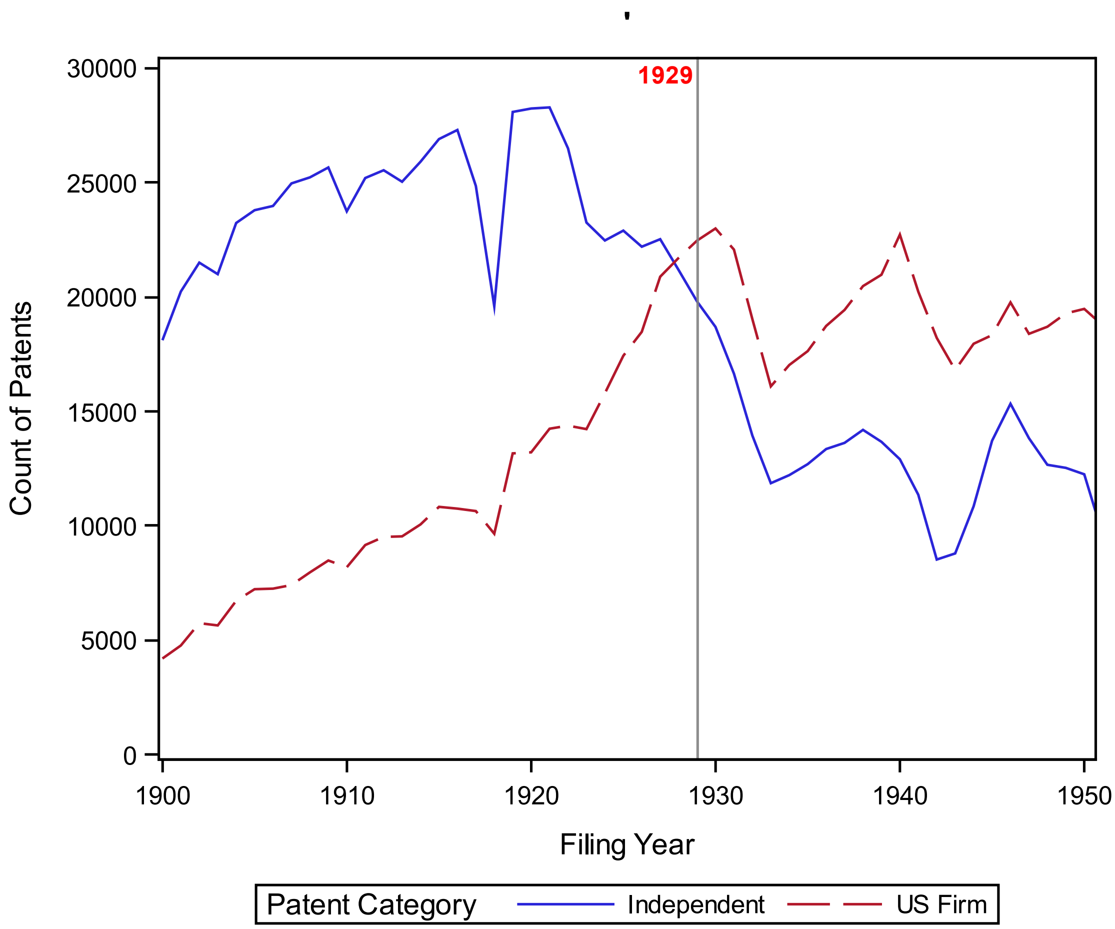


Figure 2: Independent Patents by Technology Class

The figure shows the annual number of patents by patent technology class. The technology classes correspond to the highest level of Cooperative Patent Classification (CPC) classifications by the U.S. Patent and Trademark Office (USPTO). The sample is the universe of all patents granted by the USPTO to either U.S. inventors or U.S. firms.

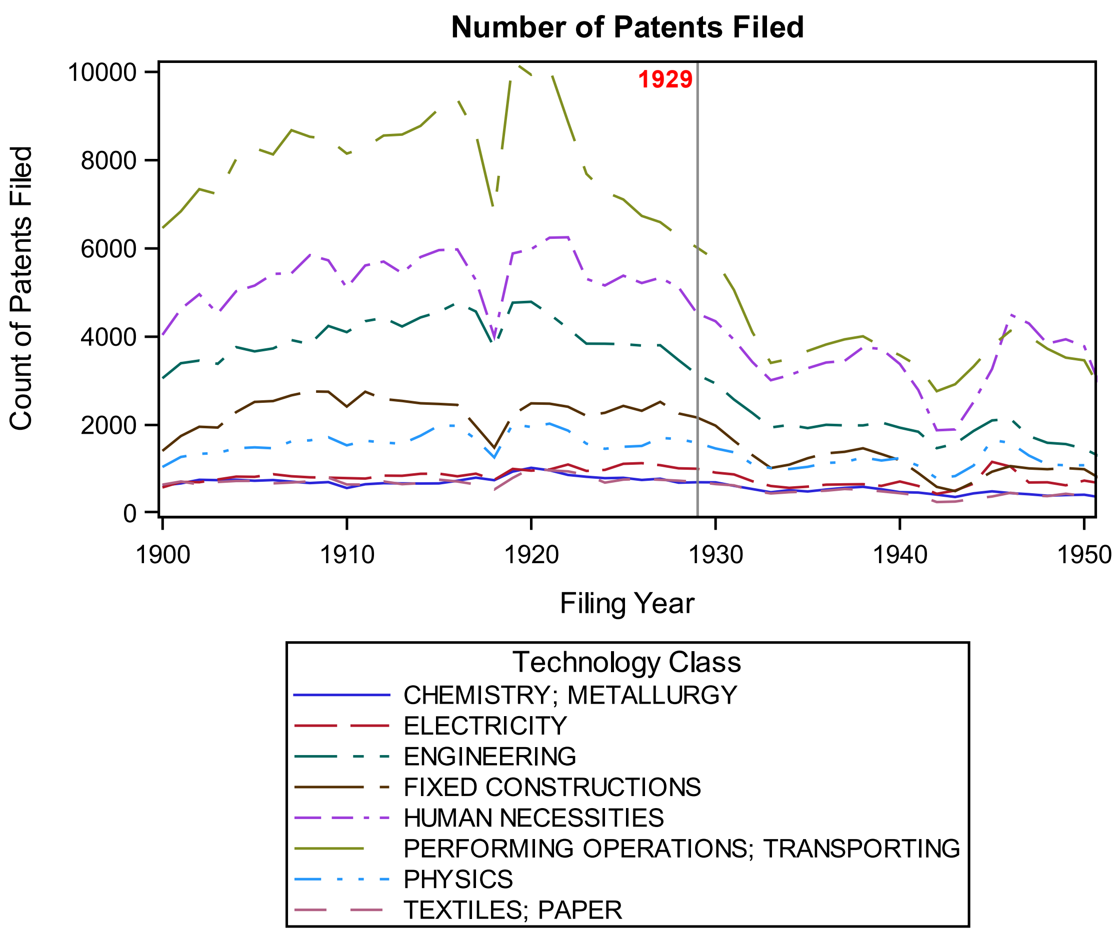


Figure 4: Bank Distress During the Great Depression and Independent Innovation Quantity

The figure shows estimates from a differences-in-differences regression of the number of independent patents on bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all independent patents granted by the U.S. Patent and Trademark Office (USPTO). Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. The unit of observation is county-time, where time is five years. The dependent variable is the logarithm of the number of independent patents filed over five-year periods within each county. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on independent innovations are the coefficients on the interaction between Bank Distress and five-year indicators that measure the relative change in patenting in areas with high bank distress relative to the reference period of 1925–1929. Specifically, we plot betas and 95% confidence intervals from a differences-in-differences regression:

$$Ln(NumberPatents)_{cst} = \alpha_c + \gamma_{st} + \sum \beta_t \, 1_t \, BankDistress_{cs} + X'_{cst}\zeta + \epsilon_{cst} \tag{2}$$

where c denotes county, s – state, and t – five-year period. α_c is county fixed effects; γ_{st} is state-time fixed effects; five-year indicators equal 1 for a given time period (e.g., 1900-04), and 0 otherwise.

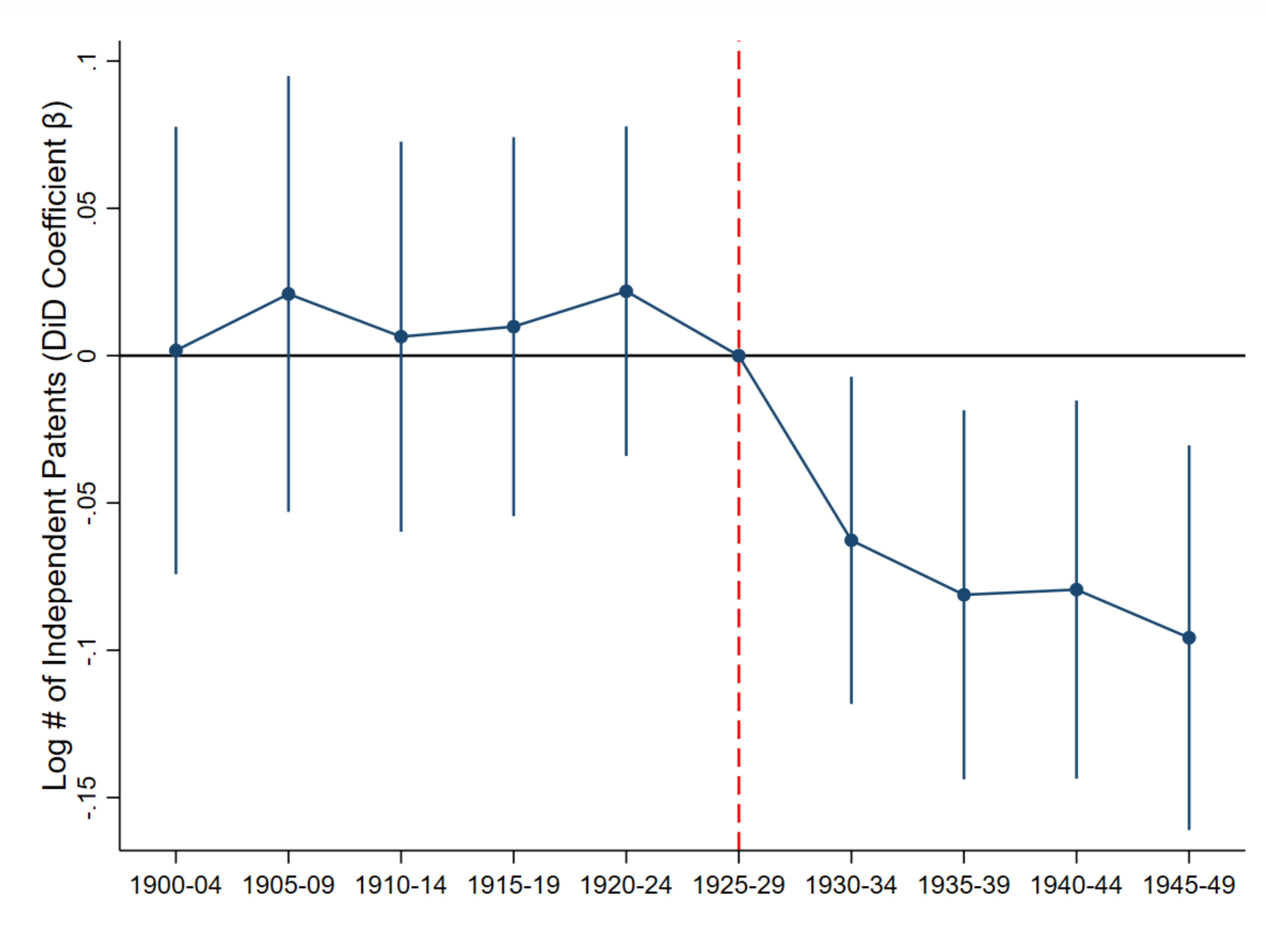
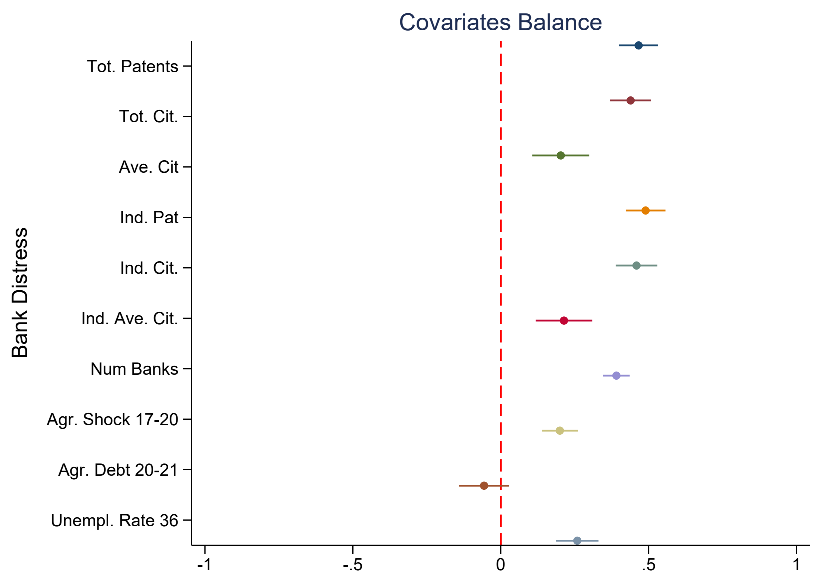


Figure 3: Covariates Across Bank Distress

The figures report the balance of covariates across two specifications: (1) controlling for state fixed-effects (part a); (2) controlling for both state fixed-effect and (log) population in 1920 (part b). Specifically, the figures report the plot of the coefficients from a regression where our main treatment variable - dummy equal one for a county with distress - on the variable reported in the legend. Each variable is z-scored to facilitate the comparison between variables. For patent counts variables, we also apply a log (plus one) transformation, consistent with the analyses in the main tables. prodOn top of the coefficient, the figure also reports the 95% confidence interval.

(a) Difference within-state



(b) Difference within-state and adjusting for population

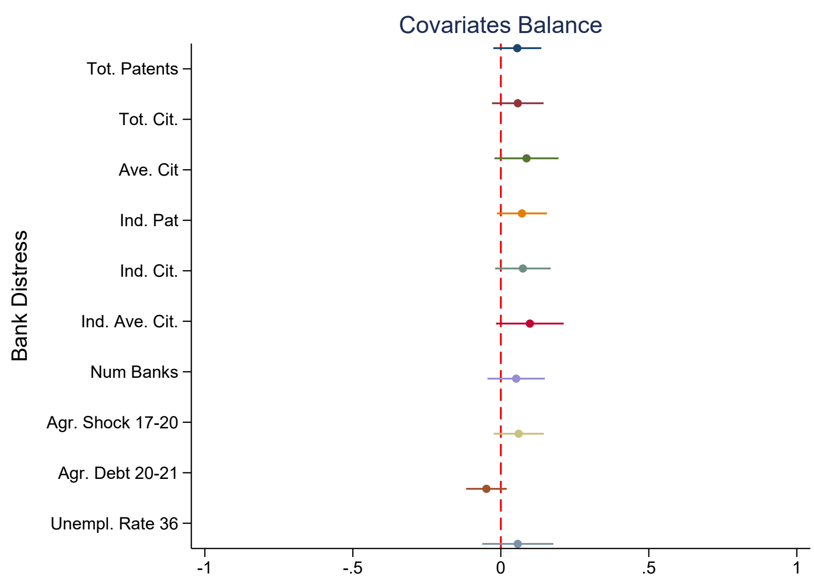


Figure 5: Bank Distress During the Great Depression and Independent Patent Quality (Total Citations)

The figure shows estimates from a differences-in-differences regression of the total number of future patent citations citing independent patents on bank distress during the Great Depression. The sample of independent patents is the universe of all independent patents granted by the U.S. Patent and Trademark Office (USPTO). The sample of future patent citations comes from the universe of all citing patents granted by the USPTO, including independent, U.S firm, and non-U.S. patents. The unit of observation is county-time, where time is a five-year period. We start the sample with the 1910-1914 period because citations data start in 1910. The dependent variable is the logarithm of the total number of future patent citations citing independent patents filed over five-year periods within each county. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on independent innovations are the coefficients on the interaction between Bank Distress and five-year indicators that measure the relative change in patenting between areas with higher bank distress relative to the reference period of 1925–1929. Specifically, we plot betas and 95% confidence intervals from the differences-in-differences regression:

$$Ln(NumberPatentCitations)_{cst} = \alpha_c + \gamma_{st} + \sum \beta_t \, 1_t \, BankDistress_{cs} + \epsilon_{cst} \quad (3)$$

where c denotes a county, s – a state, and t – a five-year period. α_c is county fixed effects; γ_{st} is state-time fixed effects; five-year indicators equal 1 for a given time period (e.g., 1910-14), and 0 otherwise.

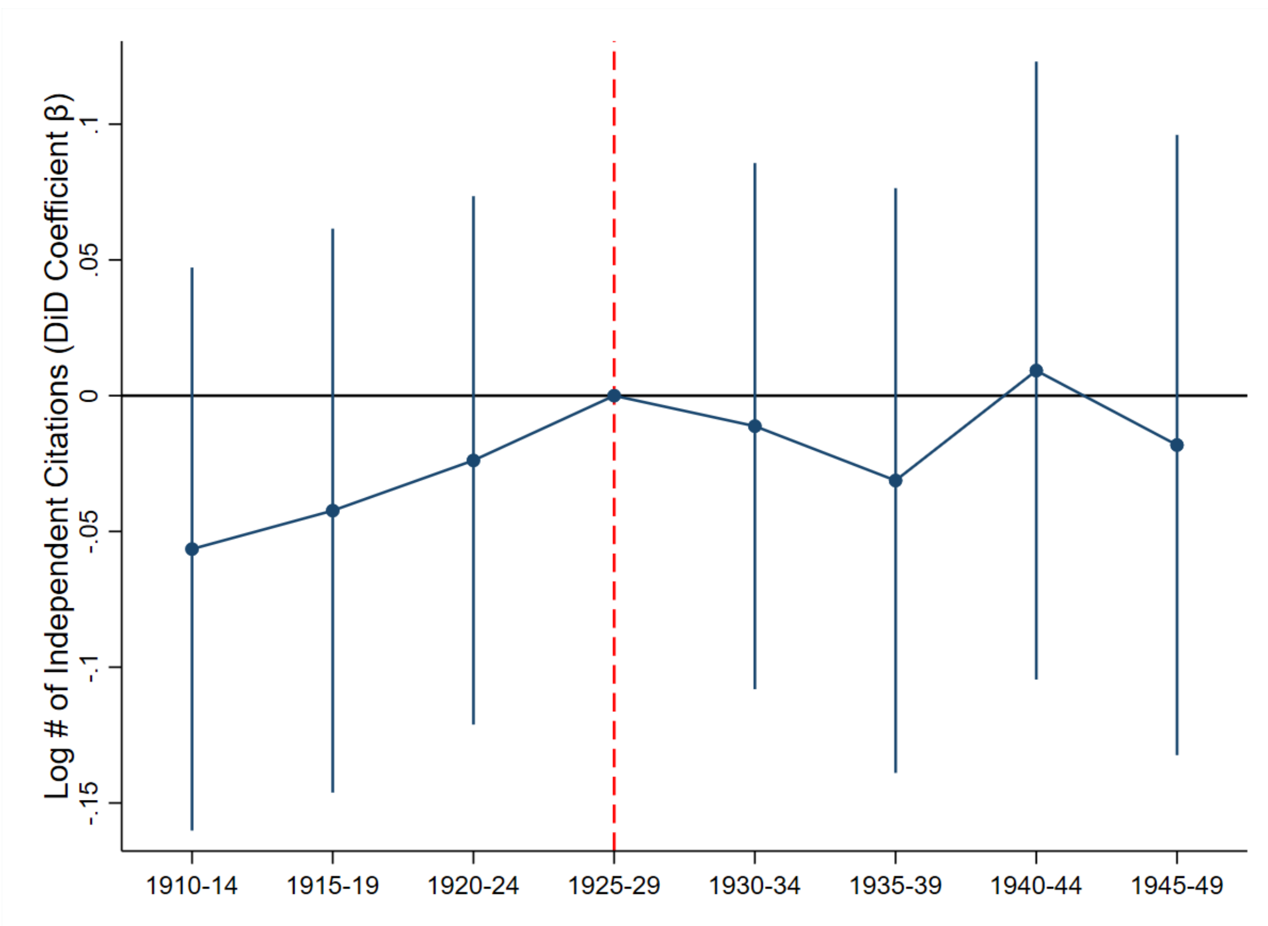


Figure 6: Bank Distress During the Great Depression and Independent Patent Quality (Average Citations/Patent)

The figure shows estimates from a differences-in-differences regression of the average independent patent quality on bank distress during the Great Depression. The sample of independent patents is the universe of all independent patents granted by the U.S. Patent and Trademark Office (USPTO). The sample of future patent citations comes from the universe of all citing patents granted by the USPTO, including independent, U.S firm and non-U.S. patents. The unit of observation is county-time, where time is five-year period. We start the sample with the 1910-1914 period because citations data start in 1910. The dependent variable is the logarithm of the average future patent citations, which is equal to the total number of future patent citations citing independent patents filed over five-year periods within each county divided by the number of independent patents. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on independent innovations are the coefficients on the interaction between Bank Distress and five-year indicators that measure the relative change in patenting between areas with higher bank distress relative to the reference period of 1925–1929. Specifically, we plot betas and 95% confidence intervals from the differences-in-differences regression:

$$Ln(AverageCitations/Patent)_{cst} = \alpha_c + \gamma_{st} + \sum \beta_t \, 1_t \, BankDistress_{cs} + \epsilon_{cst} \quad (4)$$

where c denotes a county, s – a state, and t – a five-year period. α_c is county fixed effects; γ_{st} is state-time fixed effects; five-year indicators equal 1 for a given time period (e.g., 1910-14), and 0 otherwise.

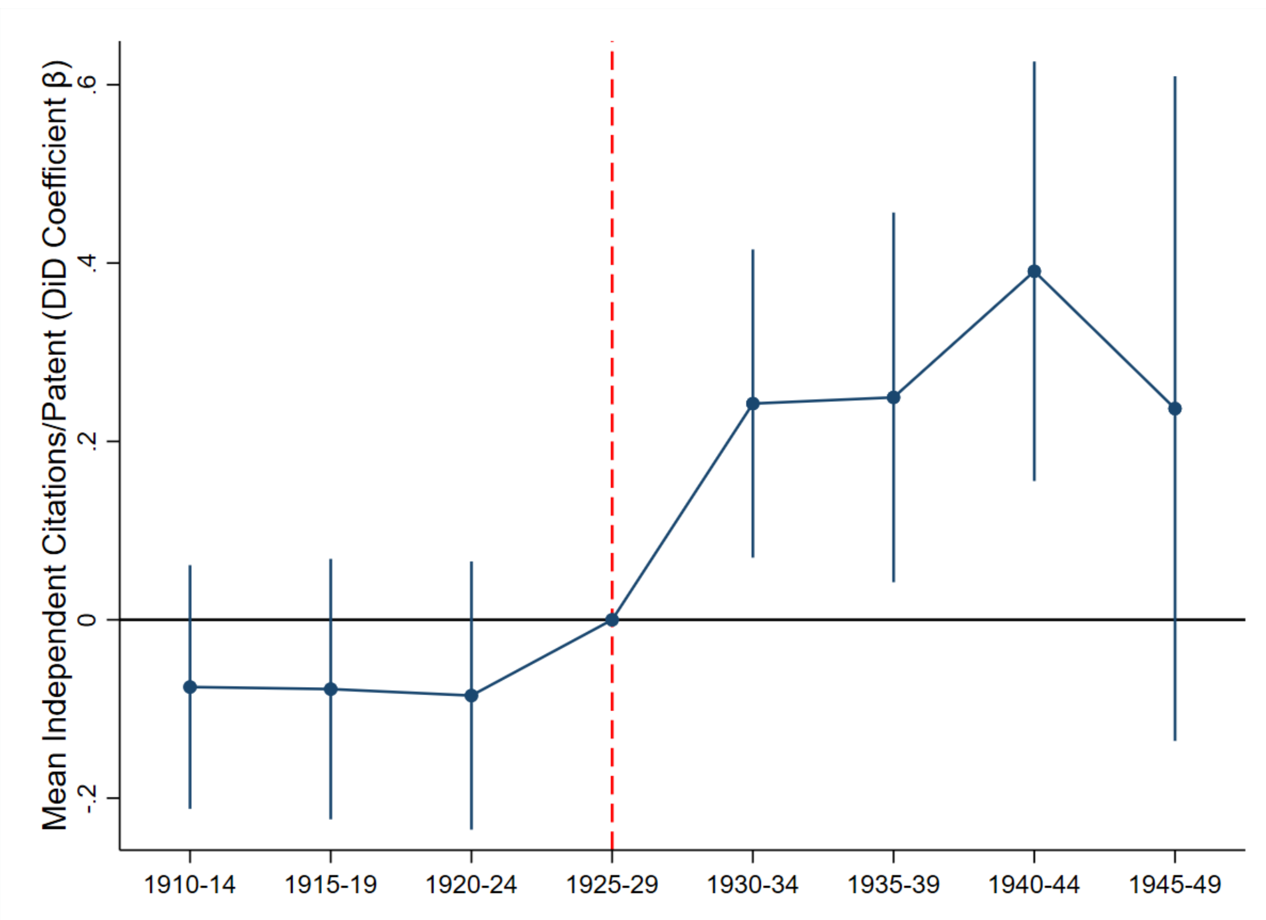


Table 1: County-Level Summary Statistics

	All Counties			*Counties w/ Suspensions*		
	Mean	Std.Dev.	NumObs	Mean	Std.Dev.	NumObs
1920s Patenting per county (log)						
Number Patents	2.72	1.63	2975	3.04	1.62	2129
Number Citations	3.24	1.96	2975	3.60	1.92	2129
Average Citations/Patent	1.00	0.47	2975	1.04	0.41	2129
Independent						
Number Patents	2.60	1.50	2975	2.90	1.48	2129
Number Citations	3.10	1.84	2975	3.45	1.79	2129
Average Citations/Patent	0.99	0.48	2975	1.03	0.42	2129
U.S. Firms						
Number Patents	1.05	1.65	2975	1.25	1.78	2129
Number Citations	1.29	2.01	2975	1.52	2.15	2129
Average Citations/Patent	0.49	0.66	2975	0.56	0.67	2129
County-level Banking Stats						
Bank Distress	0.72	0.45	2975	1.00	0.00	2129
Bank Distress %	0.30	0.28	2975	0.42	0.24	2129
Number of Banks '29	8.12	10.28	2975	9.88	11.54	2129
Misc. County Stats						
Population '20 (log)	9.81	0.98	2948	9.99	0.94	2116
Agricultural Index Chg '17-20	3.58	2.51	2829	3.90	2.58	2055
Agricultural Deb Chg '17-20	2.89	0.74	2418	2.80	0.70	1798
Unemployment Rate '36	0.01	0.01	2973	0.01	0.01	2127
Value Crops '10 (log)	14.09	1.06	2812	14.29	0.95	2051
'29-33 Chg Retail Sales	-0.48	0.23	2941	-0.49	0.21	2105

Table 2: Bank Distress During the Great Depression and Innovation Quantity

The table shows estimates from a differences-in-differences regression of the number of patents by patent type on bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. The unit of observation is county-decade, where decades include 1920 and 1930. In column 1, the dependent variable is the logarithm of the number of all U.S. patents filed over ten-year periods within each county. In column 2, we limit the sample to patents assigned to U.S. firms and define the dependent variable as the logarithm of the number of U.S. firm patents filed over ten-year periods within each county. In column 3, we limit the sample to independent patents and define the dependent variable as the logarithm of the number of independent patents filed over ten-year periods within each county. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) TotPat	(2) FirmPat	(3) IndPat
BankDistress X After1929	-0.120*** (-3.68)	-0.009 (-0.32)	-0.132*** (-4.16)
StateXTime FE	Y	Y	Y
County FE	Y	Y	Y
LHS	ln()	ln()	ln()
Start Decade	1920	1920	1920
End Decade	1930	1930	1930
Adj R-Sq	0.919	0.920	0.906
Obs	5,950	5,950	5,950

Table 3: Bank Distress during the Great Depression, Other Economic Shocks, and Independent Innovation

The table shows that the results on lower independent patenting in high bank distress counties during the Great Depression remain robust to controlling for other economic shocks. The sample is the universe of independent patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. The unit of observation is county-decade, where decades include 1920 and 1930. In columns 1 through 6, the dependent variable is the logarithm of the number of independent patents filed over ten-year periods within each county. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. In columns 1 and 2, we control for the size of counties to make sure the results are not driven by smaller counties. <6 Banks29 equals to 1 for counties with less than six banks as of 1929. LnPopulation20 is the logarithm of county's population as of 1920 U.S. census. In columns 3 and 4, we control for the county-level demand shocks to make sure the results are not driven by changes in local demand. ChgRtlSales29-33 is the county-level change in retail sales, defined as log difference in retail sales in 1933 and 1929. Unemp37 is the county-level unemployment rate during the 1937 recession. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) IndPat	(2) IndPat	(3) IndPat	(4) IndPat	(5) IndPat
BankDistress X After1929	-0.086***	-0.101***	-0.128***	-0.124***	-0.074**
	(-2.60)	(-3.02)	(-3.97)	(-3.85)	(-2.18)
LnPopulation20 X After1929	-0.090***				-0.085***
	(-5.94)				(-4.44)
<6 Banks29 X After1929		0.113***			0.026
		(3.59)			(0.71)
ChgRtlSales29-33 X After1929			-0.016		0.013
			(-0.22)		(0.18)
Unemp37 X After1929				-3.721**	-0.789
				(-2.27)	(-0.44)
StateXTime FE	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y
LHS	ln()	ln()	ln()	ln()	ln()
Start Decade	1920	1920	1920	1920	1920
End Decade	1930	1930	1930	1930	1930
Adj R-Sq	0.907	0.906	0.903	0.906	0.904
Obs	5,896	5,950	5,882	5,946	5,838

Table 4: Bank Distress During the Great Depression and Independent Innovation Across Technology Classes

The table shows estimates from a differences-in-differences regression of the number of independent patents across technology classes on bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all independent patents granted by the U.S. Patent and Trademark Office (USPTO). Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. The unit of observation is a county-decade-technology class in columns 1 and 2, and a county-decade in columns 3 through 7, where decades include 1920 and 1930. In columns 1 through 7, the dependent variable is the logarithm of the number of independent patents. In columns 1 and 2, we count patent within each county-decade-technology class. In columns 3 through 7, we limit the sample to major patent technology classes: column 3 – human necessities (CPC class A); column 4 – performing operations or transporting (CPC class B); column 5 – fixed constructions (CPC class E); column 6 – mechanical engineering, lighting, heating, weapons, blasting engines or pumps (CPC class F); column 7 – physics (CPC class G). Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) IndPat	(2) IndPat	(3) IndPat	(4) IndPat	(5) IndPat	(6) IndPat	(7) IndPat
BankDistress X After1929	-0.126***	-0.126***	-0.138***	-0.127***	-0.127***	-0.148***	-0.092***
	(-8.07)	(-8.02)	(-4.40)	(-4.05)	(-4.69)	(-5.09)	(-4.03)
StateXTime FE	Y	Y	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y	Y	Y
IndStateTime FE	N	Y	N	N	N	N	N
Industry	All	All	A	B	E	F	G
LHS	ln()	ln()	ln()	ln()	ln()	ln()	ln()
Start Decade	1920	1920	1920	1920	1920	1920	1920
End Decade	1930	1930	1930	1930	1930	1930	1930
Adj R-Sq	0.744	0.837	0.847	0.865	0.807	0.834	0.818
Obs	29,750	29,750	5,950	5,950	5,950	5,950	5,950

Table 5: Distress of National and State Banks and Innovation during the Great Depression

The table shows estimates from a differences-in-differences regression of the number of patents by patent type on bank distress during the Great Depression. In this table, we separately identify the effect of suspensions of state banks (State BankDistress) and national banks (National BankDistress). The suspensions of state bank are likely to have a direct impact on the disruption of local technological entrepreneurship because state banks played a central role in the local angel financing network. In contrast, national lenders tended to provide refinancing and other secondary lending activities, which required lower information costs. Hence, their suspensions were less likely to disrupt local financing of technological entrepreneurship. The estimation strategy relies on cross-sectional variation in distress across U.S. counties within a state across counties with more vs. less increase in leverage. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. The unit of observation is county-decade, where decades include 1920 and 1930. In columns 1 and 2, we limit the sample to independent patents and define the dependent variable as the logarithm of the number of independent patents filed over ten-year periods within each county. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. In columns 3 and 4, the dependent variable is the logarithm of the number of all patents filed over ten-year periods within each county. State (National) Bank Distress is an indicator variable equal to 1 for counties with at least one state (national) bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) IndPat	(2) IndPat	(3) TotPat	(4) TotPat
StateBankDistress X After1929	-0.077**		-0.065**	
	(-2.52)		(-2.08)	
NationalBankDistress X After1929		0.027		0.014
		(1.04)		(0.54)
StateXTime FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
LHS	ln()	ln()	ln()	ln()
Start Decade	1920	1920	1920	1920
End Decade	1930	1930	1930	1930
Adj R-Sq	0.906	0.905	0.919	0.919
Obs	5,950	5,950	5,950	5,950

Table 6: Bank Distress During the Great Depression and Innovation Quantity in the Long Run

The table shows estimates from a differences-in-differences regression of the number of patents on bank distress during the Great Depression in the long-run. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. The unit of observation is county-decade, where decades include 1920 through 1990. In column 1, the dependent variable is the logarithm of the number of all patents filed over ten-year periods within each county. In column 2, we limit the sample to patents assigned to U.S. firms and define the dependent variable as the logarithm of the number of U.S. firm patents filed over ten-year periods within each county. In column 3, we limit the sample to independent patents and define the dependent variable as the logarithm of the number of independent patents filed over ten-year periods within each county. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. In the short run, the estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for the 1930 observations. In the long run, the estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1939 indicator, which equals one for observations starting with the 1940 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) TotPat	(2) FirmPat	(3) IndPat
BankDistress X After1929	-0.120***	-0.009	-0.132***
	(-3.68)	(-0.32)	(-4.16)
BankDistress X After1939	-0.023	0.129***	-0.094***
	(-0.66)	(3.39)	(-3.05)
StateXTime FE	Y	Y	Y
County FE	Y	Y	Y
LHS	ln()	ln()	ln()
Start Decade	1920	1920	1920
End Decade	1990	1990	1990
Adj R-Sq	0.883	0.867	0.864
Obs	23,800	23,800	23,800

Table 7: Bank Distress During the Great Depression and Innovation Quality (Total Future Citations)

The table shows estimates from a differences-in-differences regression of the total number of future patent citations citing patents filed in 1920 and 1930 on bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. The sample of future patent citations includes the universe of all patents granted by the USPTO, including independent, U.S firm and non-U.S. patents. The unit of observation is county-decade, where decades include 1920 and 1930. In column 1, the dependent variable is the logarithm of the total number of future patent citations citing all patents filed over each ten-year period within a county. In column 2, we limit the sample to patents assigned to U.S. firms and define the dependent variable as the logarithm of the total number of future patent citations citing U.S. firm patents filed over each ten-year period within a county. In column 3, we limit the sample to independent patents and define the dependent variable as the logarithm of the total number of future patent citations citing independent patents filed over each ten-year period within a county. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) TotCt	(2) FirmCt	(3) IndCt
BankDistress X After1929	-0.035	0.054	-0.025
	(-0.64)	(1.08)	(-0.46)
StateXTime FE	Y	Y	Y
County FE	Y	Y	Y
LHS	ln()	ln()	ln()
Start Decade	1920	1920	1920
End Decade	1930	1930	1930
Adj R-Sq	0.852	0.855	0.828
Obs	5,950	5,950	5,950

Table 8: Bank Distress During the Great Depression and Innovation Quality (Average Citations Per Patent)

The table shows estimates from a differences-in-differences regression of the average citations per patent on bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. The sample is the universe of all patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. The sample of future patent citations includes the universe of all patents granted by the USPTO, including independent, U.S firm and non-U.S. patents. The unit of observation is county-decade, where decades include 1920 and 1930. In column 1, the dependent variable is the logarithm of the average future patent citations, which is equal to the total number of future patent citations citing the patents filed over each ten-year period within a county divided by the number of patents. In column 2, we limit the sample to patents assigned to U.S. firms and define the same dependent variable as in column 1. In column 3, we limit the sample to independent patents and define the same dependent variable as in column 1. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. The interaction measures the relative change in patenting between areas with higher bank distress relative to the 1920 decade. Controls include the logarithm of county population from the Decennial U.S. Censuses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) TotAvgCt	(2) FirmAvgCt	(3) IndAvgCt
BankDistress X After1929	0.077**	0.036	0.105***
	(2.22)	(0.99)	(2.92)
StateXTime FE	Y	Y	Y
County FE	Y	Y	Y
LHS	ln()	ln()	ln()
Start Decade	1920	1920	1920
End Decade	1930	1930	1930
Adj R-Sq	0.338	0.476	0.313
Obs	5,950	5,950	5,950

Table 9: Bank Distress During the Great Depression and Individual Inventor Patenting During the 1930s among Independent Inventors of the 1920s

The table examines the potential reallocation of independent inventors into firms during the 1930s in counties with greater bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. To test for reallocation, we limit the sample to individual U.S. inventors who: 1) had at least one independent patent granted by the U.S. Patent and Trademark Office (USPTO) during the 1920s, and 2) had at least one patent grant during the 1930s; 3) we could find the location of operation in 1920 and 1930 censuses. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. In columns 1 and 2, the dependent variable equals 1 if the inventor obtains at least one patent assigned to a U.S. firm in the 1930s, and 0 if he obtains at least one independent patent in the 1930s. Column 1 includes state fixed effects. Column 2 adds additional county-level controls (population 1920) while column 3 adds another set of individual level controls based on the 1920 census (homeownership, inventor age, stauts as an entrepreneur, and gender). Bank Distress % is defined at the county-level and equal to the ratio of bank deposits at banks suspended between 1930 and 1933 divided by total banks deposits in 1929. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) Firm Pat	(2) Firm Pat	(3) Firm Pat
Bank Distress %	0.078**	0.096**	0.090**
	(2.00)	(2.42)	(2.27)
State FE	Y	Y	Y
Patent Post	Y	Y	Y
Pre Ind Pat	Y	Y	Y
County Controls	N	Y	Y
Ind. Controls	N	N	Y
Adj R-Sq	0.020	0.021	0.027
Obs	5,295	5,294	5,294

Table 10: Bank Distress During the Great Depression and Individual Inventor Geographic Mobility During the 1930s

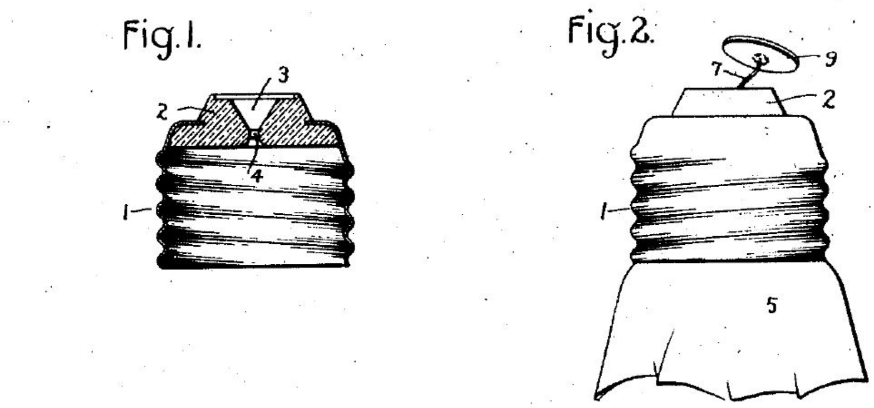
The table examines the potential geographic mobility of inventors away from counties with greater bank distress during the Great Depression. The estimation strategy relies on cross-sectional variation in bank distress across U.S. counties within a state. To test for geographic mobility, we limit the sample to individual U.S. inventors who had at least one patent granted by the U.S. Patent and Trademark Office (USPTO) during the 1930s. In columns 1 through 3, the dependent variable equals 1 if the inventor' county in the 1940 Complete Count Census is different from the county where he lived as of the 1920 Complete Count Census. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. Bank Distress % is defined at the county-level and equal to the ratio of bank deposits at banks suspended between 1930 and 1933 divided by total banks deposits in 1929. Bank Distress > Med equals 1 for counties with bank deposit suspensions above the median county's suspensions. County-level deposit suspensions is the ratio of bank deposits at banks that were suspended between 1930 and 1933 divided by total bank deposits in 1929. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) Move County	(2) Move County	(3) Move County
Bank Distress	0.003		
	(0.30)		
Bank Distress %		0.026	
		(1.30)	
Bank Distress >Med			-0.002
			(-0.21)
State FE	Y	Y	Y
Patent Pre	Y	Y	Y
Controls	Y	Y	Y
Adj R-Sq	0.030	0.030	0.030
Obs	66,693	66,693	66,693

Internet Appendix

Figure 7: Example Firm Patent

Figure shows an example of a patent assigned to a U.S. firm (i.e., General Electric) by the U.S. Patent and Trademark Office (USPTO) at the time of the patent grant. Patents assigned to firms are usually produced by inventors employed within large firms with in-house R&D labs who would have been contractually obliged to assign their inventions to their employers (Lamoreaux, Sokoloff, and Sutthiphisal 2009; Nicholas 2010).



A. SWAN.
INCANDESCENT LAMP.
APPLICATION FILED JUNE 7, 1905.

905,478. Patented Dec. 1, 1908.

UNITED STATES PATENT OFFICE.

ALFRED SWAN, OF NEW YORK, N. Y., ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INCANDESCENT LAMP.

No. 905,478. Specification of Letters Patent. Patented Dec. 1, 1908.

Application filed June 7, 1905. Serial No. 264,078.

To all whom it may concern:

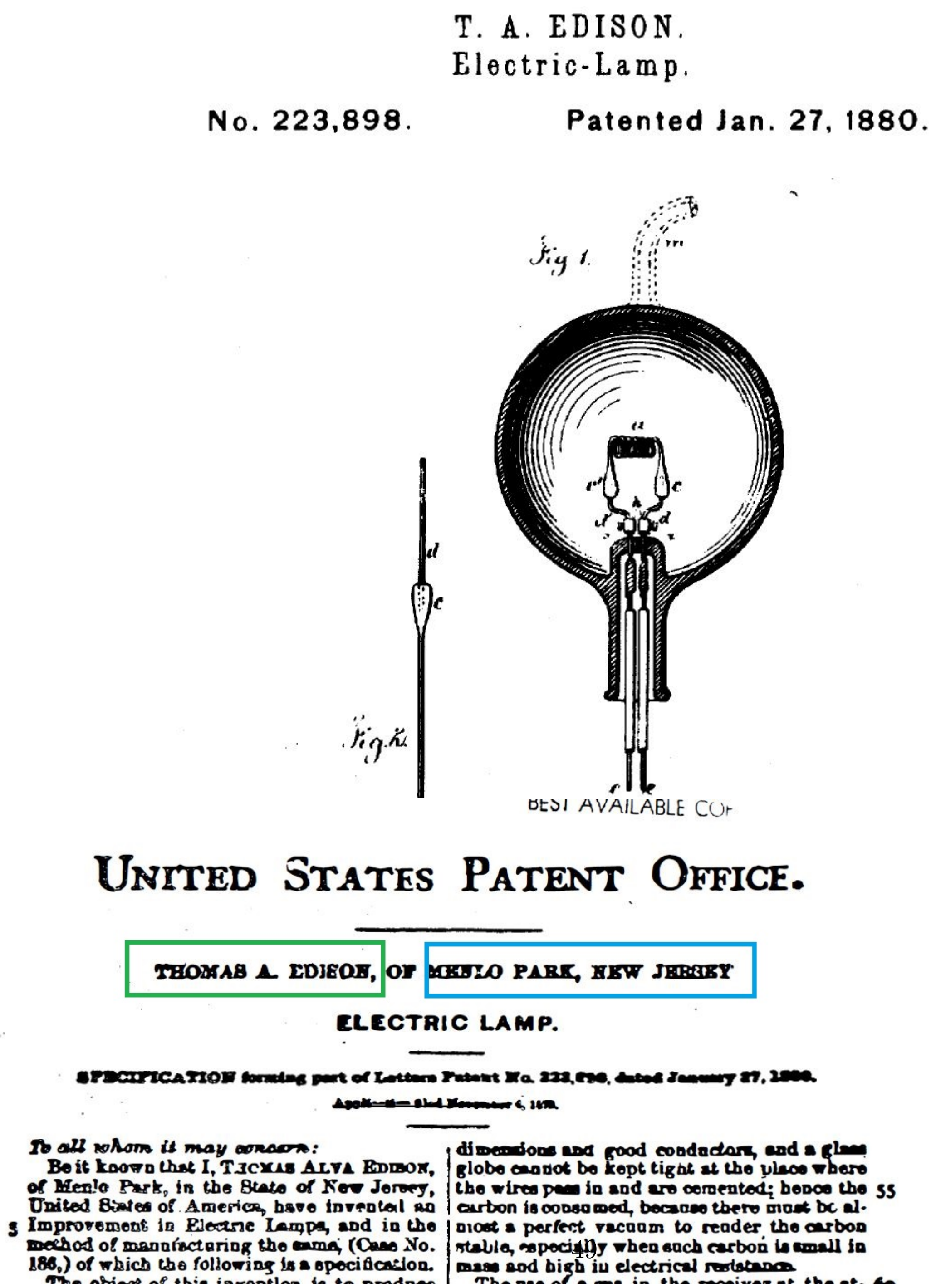
Be it known that I, Alfred Swan, a subject of the King of Great Britain, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Incandescent Lamps, of which the following is a specification.

for connecting the leading-in wire to the under side of the center contact so that the solder does not show at all from the outside and connection is made with the contact direct and not through the solder used in connecting the leading-in wire thereto.

In accordance with my invention, I form

Figure 8: Example Independent Patent

Figure shows an example of an independent issued by the U.S. Patent and Trademark Office (USPTO). The independent inventors produced inventions on their own means or through financing by local angel investors (Lamoreaux, Sokoloff, 2005; Lamoreaux, Sokoloff, and Sutthiphisal 2009; Nicholas 2010). These patents are usually either unassigned, assigned to the inventor, or other individuals (e.g., investors). Independent inventors usually either sold off their patents to large firms for commercialization or founded own startups for commercialization. The patent displayed in this figure is the famous light-bulb invention by Thomas Edison, who in 1880 founded a Edison Electric Light Company to market his hew invention.


T. A. EDISON.
Electric-Lamp.

No. 223,898. Patented Jan. 27, 1880.

UNITED STATES PATENT OFFICE.

THOMAS A. EDISON, OF MENLO PARK, NEW JERSEY.

ELECTRIC LAMP.

SPECIFICATION forming part of Letters Patent No. 223,898, dated January 27, 1880.

Application filed November 4, 1879.

To all whom it may concern:

Be it known that I, THOMAS ALVA EDISON, of Menlo Park, in the State of New Jersey, United States of America, have invented an Improvement in Electric Lamps, and in the method of manufacturing the same, (Case No. 186,) of which the following is a specification.

dimensions and good conductors, and a glass globe cannot be kept tight at the place where the wires pass in and are cemented; hence the carbon is consumed, because there must be almost a perfect vacuum to render the carbon stable, especially when such carbon is small in mass and high in electrical resistance.

Table A.1: Robustness: Different Measures of Bank Distress

The table shows that the results on lower independent patenting in high bank distress counties during the Great Depression remain robust to the measure of distress used. The sample is the universe of independent patents granted by the U.S. Patent and Trademark Office (USPTO) to either U.S. inventors or U.S. firms. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. The unit of observation is county-decade, where decades include 1920 and 1930. In all columns the dependent variable is the logarithm of the number of independent patents filed over ten-year periods within each county. In column 1 Bank Distress is an indicator variable equal to 1 for counties with an above median

	Ln(Independent Patents)			
	(1)	(2)	(3)	(4)
Bank Distress	-0.132***			
	(-4.16)			
Bank Distress (Deposits) >Med		-0.062**		
		(-2.34)		
Bank Distress (Banks) >Med			-0.053*	
			(-1.95)	
Bank Distress %				-0.104*
				(-1.94)
StateXTime FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Start Decade	1920	1920	1920	1920
End Decade	1930	1930	1930	1930
Adj R-Sq	0.906	0.906	0.905	0.905
Obs	5,950	5,950	5,950	5,950

Table A.2: Robustness: matching model

The table shows that the results on lower independent patenting in high bank distress counties during the Great Depression remain robust when we employ a matching model based on location, population, and pre-crisis patenting activity. The matching model is described in the text and the sample considered is the one that is identified following the model discussed. Independent are patents by inventors residing in the U.S. that were either unassigned or assigned to individuals at the time of the patent grant date. The unit of observation is county-decade, where decades include 1920 and 1930. In columns 1 and 2, the dependent variable is the logarithm of the number of independent patents filed over ten-year periods within each county. Instead, in columns 3 and 4, the dependent variable is the logarithm of the number of firm patents filed over ten-year periods within each county. Bank Distress is an indicator variable equal to 1 for counties with at least one bank suspension during the Great Depression years of 1930 through 1933, inclusive. The estimates of the effect of bank distress on patents are the coefficients on the interaction between Bank Distress and After1929 indicator, which equals one for 1930 observations. In odd columns there are no controls, while in even columns we control for population in 1920, unemployment rate in 1937, the log difference in retail sales in 1933 and 1929, a dummy for counties with fewer than 6 banks all interacted with the post dummy. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) IndPat	(2) IndPat	(3) FirmPat	(4) FirmPat
treatedXafter1929	-0.122** (-2.51)	-0.104** (-2.12)	-0.022 (-0.57)	-0.022 (-0.53)
StateXTime FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
LHS	ln()	ln()	ln()	ln()
Controls	N	Y	N	Y
Start Decade	1920	1920	1920	1920
End Decade	1930	1930	1930	1930
Adj R-Sq	1	1	1	1
Obs	1,918	1,856	1,918	1,856

Table A.3: Robustness: Individual Inventor Analyses with alternative treatment

The table provides a robustness test to the analysis that examines the potential reallocation of independent inventors into firms during the 1930s in counties with greater bank distress during the Great Depression. The estimation strategy is the same as before, using the same sample and same structure of the analysis. The only difference is that our treatment variable. In particular, in columns 1 and 2, we define our treatment as a dummy which is equal to one if the county had experienced any bank distress episode during the Depression. In columns 3 and 4, we define the treatment equal to one if the individual is in the top half of individuals in terms of bank distress during the Depression. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) Firm Pat	(2) Firm Pat	(3) Firm Pat	(4) Firm Pat
Bank Distress	-0.006	-0.019		
	(-0.18)	(-0.57)		
Bank Distress >Med			0.020*	0.024**
			(1.69)	(2.05)
State FE	Y	Y	Y	Y
Patent Post	Y	Y	Y	Y
Pre Ind Pat	Y	Y	Y	Y
Controls	N	Y	N	Y
Adj R-Sq	0.019	0.026	0.019	0.026
Obs	5,295	5,294	5,295	5,294

Table A.4: Bank Distress During the Great Depression and Individual Inventor Patenting: placebo analysis

The table provides a robustness on the result studying the reallocation of independent inventors into firms during the 1930s in counties with greater bank distress during the Great Depression. In particular, we try to replicate the same result as identified for 1930s for periods that came before the depression, akin to a placebo analysis. In columns 1 and 2, we examine whether inventors that were independent in 1910s and still patenting in 1920s were more likely to move into firms in the 1920s in counties that were subsequently affected by the banking shock. In columns 3 and 4, we examine whether inventors that were independent in 1900s and still patenting in 1910s were more likely to move into firms in the 1920s in counties that were subsequently affected by the banking shock. In other words, apart from the timing, the set up is consistent to the one fo the main analyses. Odd column include state fixed effects, while even columns adds additional county-level controls (population 1920) and individual level controls based on the pre census (homeownership, inventor age, stauts as an entrepreneur, and gender). Bank Distress % is defined at the county-level and equal to the ratio of bank deposits at banks suspended between 1930 and 1933 divided by total banks deposits in 1929. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1) Firm Inventor 1920	(2) Firm Inventor 1920	(3) Firm Inventor 1910	(4) Firm Inventor 1910
Bank Distress %	0.005	0.021	-0.020	0.069
	(0.20)	(0.89)	(-0.67)	(1.52)
State FE	Y	Y	Y	Y
Patent Post	Y	Y	Y	Y
Pre Ind Pat	Y	Y	Y	Y
Controls	N	Y	N	Y
Adj R-Sq	0.018	0.025	0.006	0.016
Obs	11,650	11,207	5,995	2,213