This cloud has a silver lining: economic crisis and technological exploration

Abstract

We used a large-sample inductive approach to explore the impact of economic crises and recessions on technological exploration in the regions. Exploration is associated with the creation of new technological trajectories in regions and hence their resilience. In context of the US, we show that the intensity of Financial Crisis (2007-08) and the following recession increased the incidence of regional exploration; regions which were hit the hardest by the Crisis and recession engaged in distant search the most. Subsequently, we examined three potential mechanisms that support exploration – (a) shift in the R&D emphasis of resourceful innovator firms in the region from exploitation to exploration, (b) changes in the demography of regional actors (new firms and inventors), and (c) structural changes in the regional coinventors' network, lowering hierarchy. We found empirical support for the first and the third mechanism. This paper indicates that economic crises may indeed punctuate regional evolution, and by encouraging exploration, begin a new cycle of variation, selection and retention. Examination of potential mechanisms reveals how resourceful innovator firms respond to economic crises, and how these responses have system (region) level effects, potentially in terms of specialization and resilience in the long-term. This paper also contributes to the literature on network dynamics and establishes the effects of hierarchy on region's innovation outcomes.

Keywords: Economic crisis, technological exploration, firms' R&D strategy, regional innovation network

1. Introduction

Large-scale economic crises are associated with the contraction of real GDP, crash of real assets and equity markets, decrease in productivity, and spikes in unemployment rate (Levchenko, Lewis, & Tesar, 2010; Reinhart & Rogoff, 2009; Duval, Hong, & Timmer, 2020). One of the most influential theorists of entrepreneurship – Joseph Schumpeter – who experienced Great Depression (1929-35[1]), however, remained unruffled by the incidence of such crises. He considered them as laboratories of new ideas, when much of the deadwood was cleared and entrepreneurs adopted the best innovations and practices (Schumpeter, 1939). It seems counter-intuitive and paradoxical that an event, which destroys so much wealth in the economy and brings so much hardship to the people, can have positive long-terms effects. Following the insights of Schumpeter, can we argue that economic crises and the ensuing recessions drive commitment to and production of new technologies, and thus creation of new trajectories at the organizational and regional levels? Despite its immense theoretical and policy relevance, few management and innovation scholars have examined whether, and how, economic crises affect the incidence of technological exploration. In this paper, we seek to establish this relationship empirically and understand the potential mechanisms.

Relationship between economic crises and innovation is theoretically complex; crises affect innovation through multiple mechanisms operating simultaneously, at times with opposing effects. Scholars have studied the effects of downturns on firms' R&D investments and their performance effects (Aghion & Saint-Paul, 1998; Aghion, Askenazy, Berman, Cette, & Eymard, 2012; Paunov, 2012; Archibugi, Filippetti & Frenz, 2013; Amore, 2015; Armand & Mendi,

[1] To give a perspective, between 1929 and 1932, the global GDP fell by an estimated 15%.

2018; Flammer & Ioannou, 2018). However, we know relatively less about how downturns affect the nature of technology search, whether it increases exploitation or exploration (Laperche, Lefebvre & Langlet, 2011). Another limitation of this literature is that it examines the effects of crises and recessions on innovations only on firms; it conspicuously omits region as the unit of analysis. This omission is all the more surprising as innovation in regional context is a long-established field of research and its importance has been well underlined for theory, practice and policy. Regions have their own specializations, structural features, productivity, evolution and dynamic adaptability (Bathelt & Gluckler, 2003; Boschma, 2015; Menzel & Fronahl, 2010; Keeble & Wilkinson, 1999). Regional factors also affect organizational phenomena and decisions such as inception and growth of the entrepreneurial ventures (Armington & Acs, 2002; Spigel, 2017), and location selection decisions, internal venturing, openness strategies and competitiveness of the large firms (Almeida, 1996; Whittington, Owen-Smith & Powell, 2009). Pulling out regions out of crises and recessions is a primary concern for policy makers, given their effects on welfare. During Financial Crisis (2008-09), governments at various levels acted as the lenders of last resort, bailed out illiquid firms and institutions, and devised stimulus packages (Congleton, 2009; Breitenfellner & Wagner, 2010). Policy makers are similarly engaging in and supporting technological and frugal innovations to save their societies from the COVID-19 pandemic and revive their economies (Harris, Bhatti, Buckley & Sharma 2020). Given its importance, we focus on region as a unit of analysis, and study the effects of crises and recessions on regional exploration, which contributes to a region's survival and competitiveness in the long run.

A region comprises of multiple actors which may be impacted by an economic crisis distinctly. It can possibly invoke different responses from diverse regional actors, while also influencing the interaction dynamics among them. Given the theoretical complexity about how an economic crisis influences the direction of technology search in a region, we used a large N inductive empirical approach in this paper. Our approach is similar to a few recent studies in strategy (e.g., Lyngsie & Foss, 2017; Vakili & Zhang, 2018) and innovation policy (e.g., Amore, 2015). We relied on the rich patent data to capture innovation activities, construct regional innovation (coinventors') networks, and identify technological specialization and exploration in the regions (Ter Wal & Boschma, 2009; Fleming, King & Juda, 2007; Breschi & Lissoni, 2009). Operationalizing regions in terms of Metropolitan Statistical Areas (henceforth MSA) in the United States (Singh, 2005), we first empirically validated the relationship between the intensity of Financial Crisis (2007-08) and the rate of regional exploration. To this end, we employed fixed effect panel regression model (2004-14). We complemented this analysis with a difference-in-difference approach (e.g., Vakili & Zhang, 2018) for a stronger claim of causality, exploiting differences in the severity of Financial Crises on different MSAs. Subsequently, we theoretically identified three potential mechanisms that should support regional exploration. Crises engender high uncertainty (Bloom, 2014) and adversely affect demand conditions, thereby lowering the opportunity cost of exploration and weakening firm-performance (Aghion & Saint-Paul, 1998; Aghion et al, 2012). Resourceful innovator firms respond to uncertainty and low performance by creating growth options and accentuating exploration, especially if increased exploitation doesn't restore performance (Bloom, 2014; Greve, 2003; Laperche et al, 2011). Thus, under crisis, a high concentration of patenting by resourceful innovator firms should increase regional exploration. We found evidence that the concentration of patenting by assignees during the Crisis mediated its effects on regional exploration. Secondly, we tested whether changes in the populations of inventors and organizations mediated the effects of Crisis on regional exploration. Crises create a churn in these populations by inducing firm-mortality, discontinuation of existing projects, necessity-driven new venturing, and creation of growth options by resourceful firms. New ventures (Tushman & Anderson, 1986) and cognitively unbounded inventors (Cirillo, Brusoni, & Valentini, 2014) are more likely to engage in exploration. However, we didn't get evidence that Financial Crisis and recession increased new venturing or induction of new inventors in the regions. We also postulated that crises could also create a churn in the regional innovation network. Discontinuation of collaborations in existing technology areas and formation in the new ones could lower hierarchy in the regional innovation network. Centralization supports exploitation and stifle generation and pursuance of new ideas, whereas decentralization supports exploration (Lazer & Friedman, 2007; Jansen, van den Bosch & Volberda, 2006; Lavie, Stettner & Tushman, 2010; Keum & See, 2016). We found evidence that a decrease in network hierarchy partly mediated the effects of Crisis on regional exploration.

Exploration and long-term ability to create new technological trajectories contribute to a region's dynamic adaptability and resilience (Boschma, 2015; Martin & Sunley, 2015). Understanding factors predicting regional exploration is, therefore, important from both theoretical and policy perspectives. Our paper is a contribution in this direction. By studying how regions create new development paths when hit by crises and thus generate new specializations, potentially in emerging and futuristic technology areas, we respond to the call for research on regional, organizational and network resilience (Boschma, 2015; Martin & Sunley, 2015; Kahn, Barton & Fellows, 2013; Van der Vegt, Essens, Wahlstrom & George, 2015).

The two mechanisms for which we found empirical support contribute to two further streams of research. The first stream investigates the effects of crises and recessions on firms' R&D (Aghion & Saint-Paul, 1998; Aghion et al, 2012; Paunov, 2012; Archibugi et al, 2013;

Flammer & Iaonnou, 2020). It highlights that resourceful firms, which are less dependent on external capital, increase their R&D investments during downturns, and it positively affects their performance in subsequent periods. We empirically add that these firms emphasize exploration, i.e. make R&D investments in new technology areas, during the crises. These findings are consistent with the arguments of Bloom (2014) and the qualitative evidence found by Laperche et al (2011). The second stream of works establishes the effects of structural characteristics of regional knowledge networks on innovation and entrepreneurship (Cowan & Jonard, 2004, Fleming, Juda & King, 2007; Saxenian, 1994; Stuart & Sorenson, 2007). By studying how structural changes mediate the effects of crises and recessions on regional exploration, we respond to scholars calling for research on networks from a dynamic perspective (Ahuja, Soda & Zaheer, 2012; Brenner, Cantner & Graf, 2013). Studies on network dynamics have focused primarily on organic, incremental changes (Madhavan, Koka & Prescott, 1998, Sytch & Tatarynowicz, 2014) or quantitative case studies of cluster evolution (Ter Wal, 2013). In their simulation-based study, Hernandez & Menon (2017) explored the effects of radical events such as node deletion due to exogenous conditions, on network structure. This paper adds a step forward in this direction, illustrating how economic crises can trigger changes in the structure of regional innovation networks, thereby supporting a certain kind of search efforts.

The paper proceeds as follows. The next section provides an overview of works on economic crises and their implications for innovation. We then describe the context, data and empirical methods. Subsequently, we present MSA-level results of the effect of Financial Crisis and following recession on technological exploration, first using panel regression and then difference-in-difference analysis. After documenting the effects, we examine the potential mechanisms, explaining their theoretical rationale and then presenting and discussing the empirical evidence. The final section offers concluding remarks.

2. Economic crises and innovation

Crises are rare, unanticipated disruptive events which threaten not only the life-sustaining systems, functions and critical infrastructures in a society but also its core values (Hermann, 1963; Boin 2009). Crises aggravate quickly without remedial interventions; thus, they often create panic, exert immense pressure on the decision-makers, and if not dealt effectively, erode the legitimacy of the political leadership and institutions (Christensen, Laegreid & Rykkja, 2016). Some scholars view man-made crises from a process perspective – the triggering event being an outcome of a long period of incubation which creates a crisis-fostering environment. Thus, crises result from a gradual accumulation of dysfunctions, i.e. unintended detrimental effects of purposeful social actions for actors' gains, over long time (Lodge, 2009; Williams, Gruber, Sutcliffe, Shepherd & Zhao, 2017).

Most economic crises originate in the area of finance, and therefore, are exogenous to regional innovation ecosystems and technology firms (Reinhart & Rogoff, 2008). For instance, Financial Crisis in the United States (2007-08) can be traced back to the sub-prime lending crisis (Mian & Sufi, 2009; Sanders, 2008). Similarly, the 2009 Sovereign Debt Crisis in Europe was triggered by the weaknesses in public finance of certain EU member states (Lane, 2012). Despite origin in finance, economic crises often profoundly affect the whole economy. They trigger periods of higher uncertainty (Bloom, 2014; Singh, Mahmood, & Natarajan, 2017), in which consumer demand decreases or is difficult to predict (Mian, Rao, & Sufi, 2013), cost of capital increases (Chodorow-Reich, 2014; Lee, Sameen, & Cowling, 2015), and the incidence of contractions, massive layoffs, and firm-failures increases (Bernanke, 1981; Bhattacharjee, Higson, Holly, & Kattuman, 2009; Chodorow-Reich, 2014). Governments take policy and regulatory measures to contain a crisis, reduce its deleterious effects, and stimulate and ease the recovery (Baker, Bloom, & Davis, 2016; Rodrik, 1996).

Management and organization scholars have recently started studying economic crises, primarily in context of organizational survival and strategic response. For instance, Greve & Yue (2017) have investigated what determines firms' capacity to execute collective action to tide over a looming crisis. Similarly, Dowell, Shackell & Stuart (2011) studied how corporate governance and CEO power factor in survival of the firms during financial crises. An emerging stream of works focuses on the effects of crises and downturns on firms' strategy and innovation expenditures. Crises and recessions have constraining effects on innovation, especially for less resourceful firms (Lee, Sameen & Cowling, 2015; Brautzsch, Gunther, Loose, Ludwig, & Nulsch, 2015; Paunov, 2012). However, resourceful firms in technology-intensive industries may indeed invest more (rather than less) in R&D in order to get themselves out of the crisis (Aghion, Berman, Eymard, Askenazy, & Cette, 2012; Aghion & Saint-Paul, 1998; Flammer & Ioannou, 2018). Flammer & Ioannou (2018) discovered that those firms which strategically invested more in R&D during the crisis perform better in the following years. Archibugi, Filippetti & Frenz (2013), based on the UK Community Innovation Surveys, found that the crisis led to a concentration of innovative activities within a small group of firms. Large firms with internal financial resources which were already highly innovative before the crisis increased their investments. Additionally, fast-growing new entrants also exhibited high R&D investments during the crisis. They found that firms pursuing strategies towards new products and markets development during the crisis coped better. Amore (2015) highlights learning effects in R&D

strategies during recessions: firms that invested heavily in R&D in previous downturns invest more, and more effectively in R&D in the following business downturn.

The literature reviewed so far suggests a persistence (or increase) of innovation activities, at least by some firms, during the crises despite financial constraints. However, a few questions remain unanswered. What is the nature of innovative activities during a crisis: do firms continue developing innovating in their core technologies, or they invest in promising new ones? What are the responses to and effects of the crises on innovation at the aggregate levels? Scholars have studied the effects of crisis primarily on individual firms. Given that crises often hit some regions more than others and that multiple economic and institutional actors play a role in fostering innovation, it is important to understand how crises affect innovation at the regional level. To fill these gaps, we studied how the intensity of Financial Crisis (2007-08) and the following recession affected the incidence of regional exploration, i.e. innovation in technologies in which the regional inventors had not innovated before. Once established the main effect, we sought to understand the mechanisms underpinning the observed effect.

3. Context, data and sample

3.1 Context and sources

We explored the effects of Financial Crisis in 2007-08 on innovation in the US regions, as proxied by Metropolitan Statistical Area (MSA). An MSA is a geographical entity, with an urban core with a minimum population of fifty thousand, which consists of the adjacent counties deeply integrated with the urban core socially and economically (National Longitudinal Survey, Bureau of Labor Statistics)[2]. Prior works indicate that MSAs well capture the dynamics of

[2] For example, Tucson (46040) in Arizona is an MSA with only one urban region and one county (Pima). San Francisco-Oakland-Fremont (41860), on the other hand, has three integrated urban centers and it consists of five

localized, urban innovation ecosystem, and their functioning contribute importantly to regional economic outcomes (Fleming et al. 2007; Singh, 2005).

We focus on the period 2003 – 2014[3], considering a window of five years around the Financial Crisis (2007-08). The Crisis began in the sub-prime mortgage market, with a high default rate of home mortgage sector. Equity in home is the largest asset of a median family in the US, and constitutes a major component of national wealth. Government policies tend to increase the value of existing homes and supply of the mortgages. From 1950 to 2000, the real value of houses increased by an annual growth rate of 2.75% per year. However, between first quarter of 2004 and the third quarter of 2007, the real median house prices grew by 50%. Creation of this new wealth and economic growth (increase in consumption and investments) reflected in the stock market – Dow Jones Industrial Average rose by 34% in these two and half years, in contrast to 4.42% per annum between 1950 and 2000.

Bubble in the US housing sector was driven primarily by buyers' overextension, subprime lending and speculation. Total US home mortgage lending in 2008 first quarter stood at an unprecedented level of 10.07 trillion against the GDP of 14.651 trillion USD (FRED). In newly originated securitized mortgages, subprime and near-prime mortgages accounted for 40% in 2006, against 9% in 2001. Mortgage lenders sold the mortgages as private label securities (PLS) to Freddie Mac and Fannie Mae, which pooled these mortgage-backed securities (MBS) and sold to investors. By the end of 2007, Freddie Mac and Fannie Mae owned over 300 billion USD of PLS, of which 133 billion USD were PLS backed by single-family subprime mortgages.

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counties - Alameda, Contra Costa, Marin, San Francisco, and San Mateo.
http://www.nlsinfo.org/usersvc/NLSY97/NLSY97Rnd9geocodeCodebookSupplement/gatt101.htm#cbsa8

[3] A change in MSA-delineation and code-assignment (CBSA-scheme) occurred in 2003. Census Bureau created a new standard - Core-Based Statistical Areas (CBSA) that includes both metropolitan and micropolitan statistical areas. We use regions as delineated in 2003, together with their CBSA.

By mid-2007, when the rates of mortgage loan delinquency and foreclosures escalated, the primary and secondary markets for subprime lending collapsed – rapid devaluation of MBS and the liquidity crisis for banks and financial institutions that had invested heavily in these toxic instruments led to a series of bankruptcies. AIG, Bear Sterns, Goldman Sachs, Merrill Lynch, Freddie Mac and Fannie Mae came to the brink of failure and had to be salvaged, while Lehman Brothers, with about 700 billion USD of liabilities, filed for bankruptcy on September 15, 2008. The total number of Chapter 11 cases filed increased from 1583 in 2007 Q3 to 3175 in 2008 Q4. Stock markets soon caught the crisis – Dow Jones Industrial Average index plummeted from 17273.21 in October 2007 to 8623.84 in February 2009. US GDP growth declined from 1.876% in 2007 to -2.537% in 2009. The unemployment rate shot up from 4.7% in September 2007 to 10% in October 2009. Technology firms across industries, such as Hewlett Packard, Verizon, AT&T, GE, Sun Microsystems, Pfizer, Merck, Boeing, GM and Ford, undertook substantial downsizing (McIntyre, 2010).

As the mortgage lending dried up – the median housing prices slid down by 19.036% between 2007 Q1 and 2009 Q1, with significant variation at the regional level. Thus, there was a regional variance not only in the destruction of household wealth and a decline in the consumption, but also in the perception of crisis and the resultant uncertainty among market and institutional actors and people in general. To understand the impact of Financial Crisis on each MSA, we combined data on housing prices from Federal Housing Finance Agency, macroeconomic and political economic data at the state and the MSA levels from US Census Bureau and US Bureau of Economic Analysis, and patent data from the USPTO. We used patent data to capture innovation activities in each MSA. Patent data have been considered a reliable indicator of regional innovation (e.g., Bottazzi & Peri, 2003; Breschi & Lenzi, 2015; Fleming et al, 2007; Singh, 2005; Montresor & Quatraro, 2017). We retrieved the patent data from Patents View and using the information of inventors' location, assigned patents to each MSA (Breschi & Lenzi, 2015; Singh, 2005; Crescenzi, Max & Rodríguez-Pose, 2016). We created the variables the application date of the granted patents in order to capture the time when the technology was invented and the related innovative activities took place in a region.

3.2 Variables

Dependent variable. Technological exploration and exploitation have been conceptualized in terms of distant and local search (Katila & Ahuja, 2002). Exploitation implies search for solutions in the vicinity of actor's preexisting knowledge-base, and involves innovating along the pre-existing technological trajectories (Cyert & March, 1963; Lopez-Vega, Tell & Vanhaverbeke, 2016; Nelson & Winter, 1982; Rosenkopf & Nerkar, 2001; Stuart & Podolny, 1996). Exploration implies "pursuit of new knowledge" (Levinthal & March, 1993), and involves an actor's search for alternatives on new or unrelated technological trajectories or markets (Lopez-Vega et al, 2016). Thus, if an innovation belongs to a technology area in which regional inventors have already innovated, it represents local search (exploitation). In contrast, if no regional inventor innovated in that technology area, i.e., it is new or unrelated to region's knowledge base, the innovation represents distant search (exploration).

We used US patent classification (USPC) to identify whether an innovation belongs to a new or unrelated technology area from a region's perspective. USPC classifies each patent into at least one main class and within it, at least one subclass. By examining such class-subclasses assignment of all patents filed from a region, one can identify region's technological knowledge-base (Fleming & Sorenson, 2001; Rosenkopf & Nerkar, 2001). Based on these premises, we reasoned that if no regional inventor filed patents in a technology main class in the last ten years[4], the region doesn't possess knowledge-base in that broad technology area. Therefore, if an inventor from the region innovates in such technology area, he (she) is engaging in distant search (exploration). Our dependent variable is the share of exploratory inventions in all patents filed from the region in that specific year.

Independent variable. We capture the intensity of 2007-08 Financial Crisis in regions through changes in the housing price index (hereafter HPI) at the MSA level. The bursting of housing bubble, which had grown since late 1990s and peaked in 2006-07, was the first visible consequence of the subprime crisis and of its impact on regions (Sanders, 2008). Prior works also used housing prices as an indicator of the intensity of crisis in the regions because it correlated strongly with the changes in consumer demand, employment growth, and wages at the US county-level (Adelino, Schoar, & Severino, 2015; Mian & Sufi, 2014). Scholars in the fields of economics and finance also use housing price elasticity to measure the variation in the severity of recession (Giroud & Mueller, 2015). We obtained the MSA-level quarterly data on the movement of housing price index from Federal Housing Finance Agency, and took its mean for the year. The origin of Financial Crisis also indicates that it was an exogenous shock to regional innovation. For robustness check, we took the GDP per capita to capture the Financial Crisis and recession (Bloom, 2014).

Controls. We controlled factors which influence regional innovation and potentially exploration. Structural characteristics of region's innovation network are known to influence its innovative performance. Size of the network, i.e., number of inventors, is indicative of region's intellectual

[4] Technologies evolve over time – and a region's (organization's) knowledge and competencies in a technology area gradually become redundant if it is not continually generating new knowledge in that area. A gap of ten years in patenting in a technology class is good to suggest that the region's knowledge-base in the technology area is non-existent or redundant for all practical reasons. Further, if we don't take a ten-year window, more exploration will be reported in early years, e.g., in 1992 than in 2017.

resourcefulness. A large network of inventors signifies that the region is a central technopole, with deep organizational and technical competencies, superior endowment of supportive institutions, and a strong learning dynamic (Todtling & Trippl, 2005). Such regions exhibit higher efficiency in technology development (Antonelli, 2000) and commercialization (Song, Min, Lee & Seo, 2017; Min, Kim & Swang, 2020). Since the size-distribution is highly skewed in our dataset, we took its natural log.

We control for two structural characteristics of the regional networks, *viz*., connectedness and density, while test the third (hierarchy) as a mediating mechanism for the effect of Crisis and recession on regional exploration. Dense, connected networks are efficient for disseminating information and transferring complex knowledge. However, inefficient networks are supportive of exploration. Fragmentation and isolation of sub-groups sustain diversity in the regional network and enable parallel search and recombination (Lazer & Friedman, 2007; Fang, Lee & Schilling, 2010; Funk, 2014). Shorter path lengths and larger connected components positively affect region's innovation performance (Fleming et al, 2007). We also control for the external orientation of regional inventors (ratio of external and internal collaboration ties). Inventors located in regions with high density of research institutions and firms tend to source knowledge internally, whereas those located in peripheral regions with weaker innovation ecosystems exhibit a higher external orientation (Perkmann, 2006; Todtling, Lengauer & Hoglinger, 2011). Between regions of comparable innovation profile, a higher external orientation may imply access to diverse knowledge resources, possibility of boundary-spanning between communities of inventors from different regions, and higher potential of commercializing the innovations.

Technological, economic and institutional profile of the regions constitute another set of controls. Region's specialization in a certain industry has an inverse U relationship with innovation efficiency due to an interplay between Marshallian and Jacobian externalities (Fritsch & Slavtchev, 2010). However, narrow specialization technological specialization can have lock-in effects, and can inhibit distant search and novel recombination. We operationalize region's specialization/diversity by measuring the concentration (Herfindahl Hirschman Index) of patenting by technologies (USPC main classes). Size of high-tech industries and quality of human capital in these industries signify technological competence of the regions, and are hence controlled (Sleuwaegen & Boiardi, 2014). Further, region's public expenditure on higher education affect its innovativeness. Higher education contributes to regional innovation directly by creating valuable scientific knowledge, and indirectly by inducing industrial R&D investments in the region (Anselin, Varga & Acs, 1997; Jaffe, 1989; Sleuwaegen & Boiardi, 2014). Table 1 summarizes our main constructs and controls, their operationalization, and details of the data sources. We also control for the number of patents the region files in each USPC main-class in the given year and the year dummy to account for unobserved trends affecting regional exploration.

Insert Table 1 about here

3.3 Econometric model

We propose two research designs to test our framework. First, we estimated a panel regression, with MSA-fixed effects (Fleming et al. 2007). Although this approach does not allow us to fully address the problem of unobserved heterogeneity, it can help us unveil the associations between constructs of interest in our hypotheses. The equation we estimated reads as follows:

$$Exploration_{it+1} = \beta_0 + \beta_{1.}Shock_{it-2} + \alpha Z + \varepsilon_{it} \quad \dots (1)$$

We used a one-year lag between the dependent variable (exploration) and the control variables, and further two years lag with the crisis. The choice is based on evidence that the housing price crash was triggered by the subprime crisis, which took some time to show effects on the whole economy (OECD 2008)[5]. Figure 1 exhibits the temporal trends of declines in HPI in the MSAs and the US GDP – it is evident that the latter followed the former with a lag of about one year. Housing prices crashed in 2007 whereas the US GDP started witnessing decline in 2008. Firms and inventors would take further time to respond to the crisis by reorienting their innovation strategies and collaboration networks, and file patents. For robustness analysis, when we use MSA level GDP per capita (Bloom, 2014), we take a lag of one year ($Shock_{it-1}$). Notably, the GDP recovered faster than the housing prices; however, the latter manifested the optimism of consumers and investors, and influencing the psychology of (perception of Crisis by) the regional actors more directly. All variables are standardized so that the coefficient-size is easier to interpret.

Insert Figure 1 about here
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4. Results

4.1 Descriptive statistics

As a starting point, we did the descriptive analysis in order to see the distribution of each variable. It is presented in table 2. On an average, 14.1% innovations represent exploration in terms of distant search from the regional perspective. Housing Price Index was 100 for each

[5] OECD Report: http://oecdobserver.org/news/archivestory.php/aid/2753/From_the_financial_crisis_to_the_economic_downturn.html

MSA in the first quarter of 1995. Its mean value for our period was 169.087. Mean per capita real GDP (chained 2009 USD) across MSAs is 41650.38, whereas the mean salary in high-tech industries was 49732.14 USD. New assignees in the region accounted for 29.375% of the total innovations in the region.

Insert Table 2 about here

After running the full panel regression, we generated correlation matrix, presented in Table 3 below. As we can notice, correlation between the independent and the control variables is low.

Insert Table 3 about here

4.2 Panel regression with fixed effects and sensitivity analyses

Table 4 presents our main results. Model 1 and 2 predict the rate of exploration in the MSA. Model 1 includes the control variables, which can theoretically explain innovation and exploration in the regions. As expected, large, hierarchical networks which are less supportive of exploration. Coefficient of the natural log of network size is -0.5228 (p=0.000). Quality of human capital in the region significantly predicts regional exploration (coefficient: 0.0870; p= 0.000). Other controls have small and non-significant effects; however, their directions are in line with expectations. In model 2, we introduce the independent variable – housing price index (HPI). We find that HPI negatively affected regional exploration (coefficient: -0.0703; p= 0.000). It implies that regional exploration is counter-cyclical – its incidence increases during economic crises and recessions.

Insert Table 4 about here

Model 3 presents the results of robustness analysis done with per capita GDP of MSAs as a proxy of the intensity of Financial Crisis and the following recession in the regions. Per capita GDP in MSA had a significant negative effect (coefficient: -0.0698; p: 0.036) on regional exploration. Thus, Crisis and recession had a positive effect on exploration.

For robustness of our results, we controlled further policy measures, such as public capital outlays and spending on public services. The effects were not significant, and for the sake of parsimony, we didn't include them in our final analysis. We also sought to control the disbursement of public funds in regions through American Recovery and Reinvestment Act (ARRA), 2009. However, the data seems fragmented – we have missing values for almost two-thirds of observations.

4.3 Assessing causality

Though Financial Crisis was exogenous to high-tech sector, and there is a lag of three years between the movement of housing price index in a region and the effects on exploration in terms of patenting, there can be concerns of some omitted variables which might affect both our independent and dependent variables. For a stronger claim that economic crisis causes a higher incidence of regional exploration, we use difference-in-difference design by comparing regions that were hit severely by the Crisis with those which were not so severely hit (Vakili & Zhang, 2018). Difference-in-difference has been used in natural experiments and captures the differential effects of a treatment on the experimental versus the control group. It requires measuring the dependent variable for both groups before and after the treatment. To create the treatment group, we first computed the drop in housing prices in each MSA between 2007, when the prices were at the peak before Crisis, and 2011, when the prices were at the lowest. Depending on the percentage drop in prices by 2011 from 2007, the MSAs were divided into two halves. A dummy 'Hit by Crisis' was created with value 1 for MSAs that experienced higher than median drop in housing prices. Subsequently, we created the time-dummy for the Crisis and recession years. As evident from Figure 1, the housing prices registered first decline in our annual data in 2008 and didn't start recovering across MSAs till 2013. Hence, in our dataset, Crisis & recession spanned from 2008 to 2012; following our lag structure, the time-dummy is 1 (t=1) for years 2010-2014 (equation 1). Results of the analysis are presented in Table 5.

Insert Table 5 about here

In line with our argument, MSAs that were severely affected by the crisis (hit = 1) exhibited a higher incidence of exploration during the Crisis & recession period (t = 1). Model 4 shows a declining trend in regional exploration over time; the years 2010-14 predicted a decline in exploration with a coefficient-size of 0.8238 (p: 0.000). It is because of the way distant search in the regions is operationalized. We identified, rather conservatively, only the first patent in a technology main class from the region as exploration, all the subsequent patenting in that class is identified as exploitation. In Model 5, we introduced the interaction between crisis years and the MSAs which were hit severely by the crisis. The period 2010-14 has a negative effect on the incidence of distant search in regions (coefficient: -0.8871; p= 0.000). However, MSAs that experienced above-median shock (Hit = 1) engaged significantly more in distant search (coefficient: 0.1282; p= 0.000). These results strengthen the argument of causality between economic crisis and regional exploration.

5. Exploring potential mechanisms

Having established a robust positive effect of Financial Crisis (and recession) on regional exploration, we examined three theoretically informed potential mechanisms which can explain the relationship.

5.1 R&D strategy of resourceful innovators

Economic crises and recessions may induce a strategic shift in resourceful innovator firms from exploitation to exploration. Downturns adversely affect demand conditions and firms' performance. When its performance declines below aspiration levels, a firm undertakes problemistic search, and accentuates exploration, especially when increased exploitation doesn't restore its performance (Cyert & March, 1963; Greve, 2003). As exploitation doesn't pay off under weak demand, the opportunity cost of undertaking exploration is also lower (Aghion & Saint-Paul 1998; Aghion et al, 2012). Additionally, economic crises and recessions increase macroeconomic and microeconomic uncertainty, which incentivizes firms to create "growth options" in emerging and futuristic technologies (Bloom, 2014; Bloom, Floetotto, Jaimovich, Saporta-Eksten & Terry, 2018). Exploratory tendencies are pronounced in R&D-intensive firms as growth options increase their valuation (Kraft, Schwartz & Weiss, 2017). In a qualitative study, Laperche, Lefebvre & Langlet (2011) reported that during Financial Crisis, French incumbents aggressively pursued green technologies which could help them develop and dominate new niches. Thales focused on lowering CO_2 emission from aircrafts; ArcelorMittal and Saint-Gobain shifted their R&D towards developing environmentally sustainable products and processes. Similarly, automobile firms entered the segments of electric (Renault) and hybrid (PSA) cars.

Thus, while high concentration of resourceful firms would normally negatively affect regional exploration (Denrell & March, 2001; Henkel et al., 2015; Tushman & Anderson, 1986), it should positively predict it during Crisis and recession (Greve, 2003; Aghion et al, 2012; Bloom, 2014). We computed concentration of resourceful innovators by Herfindahl-Hirschman Index (HHI) in patenting by assignees in the region. As we argue that such firms change their R&D strategy during Crisis, we created dummies for the Crisis and recession years (t-1 = 2007, 2008, 2009 and 2007-2012) [6]. We test the effects of interaction term of HHI-assignees and crisis year dummies on regional exploration.

$$Exploration_{it+1} = \beta_0 + \beta_{1.}Crisis\ year_{t-1} + \beta_{2.}HHI\text{-}assignees_{it} + \beta_3(Crisis\ year_t * HHI\text{-}assignees_{it}) + \alpha Z + \varepsilon_{it} \qquad \ldots (2)$$

Insert Table 6 about here

We find that while concentration of patenting by assignee firms, i.e., presence of resourceful innovator firms, normally had a negative effect on regional exploration, their concentration during the Crisis years had a positive effect. Effects of the interaction term are strongest at the onset of Crisis (Models 6 and 7), i.e., 2007 (coefficient: 0.1831; p: 0.000) and 2008 (coefficient: 0.1858; p: 0.000). The effect size becomes smaller for 2009 (Model 8) (coefficient: 0.1038; p: 0.014). If we take the whole period of 2007-12 as Crisis & recession period, the effect-size is even smaller (Model 9) (coefficient: 0.0413; p: 0.058). It is because

[6] R&D-intensive resourceful firms have necessary systems, processes and capabilities to innovate and file patents speedily (Eisenhardt, 1989; Kessler & Chakrabarti, 1996). They also have strategic reasons to speed up innovation and patenting. Value of an option is inversely proportional to the time elapsed between initial investment and the start of positive cash flow; hence, delay would decrease the value of firms' growth options (McGrath, 1997). Payoffs of speeding up innovation and patenting are higher in emerging technologies (Munari & Toschi, 2014; Toivanen & Novotny, 2017). Hence, we modified the lag between Crisis and regional exploration from 3 to 2 years.

firms adapt their aspiration levels over time, wearing down the intensity of problemistic search (Cyert & March, 1963). Further, the process of variation (exploration) is followed by selection and retention (exploitation). If a firm has created some growth options, it tends follow them with further innovation and patenting in those technologies. While firm's first patent in a growth option technology (USPC main class) is counted as exploration (if no previous inventor from the region filed patent in that technology), the subsequent patenting in that technology is not counted as exploration in our dataset. Overall, the results suggest that resourceful innovators emphasize exploration during Crisis, and higher their concentration in regional innovation in these times, higher is the incidence of exploration.

We further tested whether concentration of resourceful innovators in region's patenting during Crisis mediates the latter's effect on regional exploration. The mediating variable is operationalized as interaction between HHI of patenting by assignees and the crisis year. For this analysis, we focus only on the onset of Crisis (t-2 = 2007).

$$Exploration_{i\ t+1} = \beta_0 + \beta_1 Shock_{i\ t-2} + \beta_2\ (Crisis\ year_t * HHI\text{-}assignee_{it}) + \alpha Z + \varepsilon_{it} \qquad \ldots (3)$$

Insert Table 7 about here

Table 7 presents the analyses. HPI (opposite of Crisis and recession) has a negative significant effect (coefficient: -0.1269; p= 0.000) on the concentration (HHI) of assignees in regional innovation in the Crisis year (Model 10). It is consistent with the literature as resourceful firms tend to increase their R&D investments during such periods (Aghion & Saint-Paul, 1998; Aghion et al, 2012; Archibugi et al, 2013; Flammer & Iaonnou, 2020) whereas firms dependent on external funding indeed reduce innovation (Lee et al, 2015; Brautzsch et al, 2015;

Paunov, 2012). Model 11 tests whether including the mediating variable (HHI assignees during Crisis year) as a factor in the equation reduces the effect-size of Crisis and recession on regional exploration. Our mediating variable has a significant positive effect (coefficient: 0.0506; p= 0.000) on regional exploration. Effect-size of HPI on regional exploration was increased from -0.0703 (p: 0.000) (Model 2) to -0.0636 (p= 0.000). We conducted Sobel-Goodman mediation analysis (Table 8) and observed that the 9.167% of the total effect of Crisis on regional exploration was mediated through increased HHI of assignees (year 2007). The coefficients of direct and mediated effects are -0.0636 (p: 0.000) and -0.0064 (p: 0.000) respectively.

Insert Table 8 about here

Economic crises and recessions may lead to firm-failures, termination of several exploitation-related projects, new venturing, especially necessity-driven entrepreneurship, and starting of new exploratory projects. These developments influence both the demography of regional actors, and the patterns of collaborations. Hence, we tested two potential mechanisms – entry of new regional actors (organizations and inventors), and change in the hierarchy of regional innovation (coinventors) network.

5.2 Entry of new inventors and ventures in the region

Distant search in a region can be brought by the inventors coming from outside the MSAs. Knowledge is predominantly tacit in the early stages of technology life-cycle and hence embedded in the inventors. Their mobility is an important conduit of knowledge-flow into the region (Breschi & Lissoni, 2009; Song, Almeida, & Wu, 2003; Singh & Agrawal, 2011). Entry of new-generation inventors specializing in emerging technologies may also influence regional exploration. Accordingly, we created a variable – "newness of the inventors in the region" to capture patenting experience of the most junior co-inventor from the region. For instance, if a patent is filed by a single inventor, who is highly experienced – the patent is his 120th innovation, but he has newly relocated to the MSA, from where it is only his 2nd filed patent, the variable "newness of inventors in the region" will compute the experience 2 and not 120. Similarly, suppose two more inventors – one from the region (8th patent from the region) and the other from outside the region (22nd patent) – have patented the innovation mentioned above. The newness variable still reads 2. Thus, the variable captures how from much new insight, from region's perspectives, was infused for the innovation.

Similarly, a change in organizational population can affect regional exploration. New ventures have higher incentives and abilities to undertake exploration (Henkel, Ronde & Wagner, 2015; Tushman & Anderson, 1986). Even when an inventor leaves a firm and starts a new venture (new assignee) or applies for patent-rights as individual assignees (potentially pre-incubation stage), he is more likely to engage in distant searches because of de-socialization and cognitive unbounding (Cirillo, Brusoni, & Valentini, 2014; March, 1991). On the other hand, large incumbents tend to favor exploitation (Denrell & March, 2001; Tushman & Anderson, 1986). We capture entries through the share of patenting by the first-time assignees. It proxies three conditions: (1) *de alio* entries into the region, (2) *de novo* ventures in the region, and (c) first-time individual assignees (potentially pre-incubation stage ventures). All these can favor distant search from the regional perspective.

We first tested whether Financial Crisis and recession had positive effects on the two variables, viz., newness of inventors and entrepreneurial entries.

$$\textit{Newness of inventors}_{it} = \beta_0 + \beta_{1.}\textit{Shock}_{it-2} + \alpha Z + \varepsilon_{it} \qquad \ldots (4)$$

$$Entrepreneurial\ entries_{it} = \beta_0 + \beta_1.Shock_{it-2} + \alpha Z + \varepsilon_{it} \qquad \ldots (5)$$

Insert Table 9 about here

In Table 9, Models 12 and 13 respectively present the effects of Financial Crisis and recession on the entry of inventors and organizations in regions. Model 12 shows that HPI had a non-significant effect (coefficient: 0.0067; p= 0.698) on inventors' mean newness. It seems that Crisis and recession didn't affect the inward mobility of inventors into the region or the induction of new-generation inventors. Indeed, sign of the coefficient suggests that inwards mobility and induction of new generation inventors take place when the economic situation are favorable. Similarly, Model 13 shows that HPI had a positive but non-significant effect on the entry of technology ventures (coefficient: 0.0152; p= 0.386). Crisis might lead to necessity-venturing by displaced inventors in the region (Dahl & Sorenson, 2010), but it seems largely inconsequential for regional innovation, at least in terms of patenting. Entries and innovation by new ventures may also be fewer because of their dependence up external funding and higher costs of capital during crises and recessions. Thus, we can argue that regional exploration during crises and recessions is not spearheaded by the entry of new inventors or ventures.

5.3 Structural change in region's innovation network

Search processes are facilitated and constrained by network-structure (Sparrowe, Liden, Wayne & Kraimer, 2001). Network studies provide ample evidence that exploration and distant search are favored by flatter structures. They support diverse worldviews and parallel search processes, leading to greater exploration (Carnabuci & Operti, 2013; Lazer & Friedman, 2007). Studies indicate that hierarchy or centralization negatively impact improvisation, idea-generation and performance in highly exploratory contexts (Keum & See 2016; Sparrowe et al, 2001). Based on these works, we examined whether crisis-induced structural changes in the regional innovation networks is a mediating mechanism.

We operationalize our mediating variable – *hierarchy of the regional innovation network* – in terms of degree centralization of region's innovation network (Chang & Shih, 2005). Centralization is a whole-network property, which denotes the extent to which the network is organized around its most central node (Freeman, 1979). It is measured by calculating the sum of the difference in the centrality of its most central node and all other nodes in the network, and then dividing it by the theoretically largest sum of the differences (Borgatti, Everett, & Johnson, 2018). Thus, network-centralization C_x is measured as follows, when p_m is the node with highest centrality.[7]

$$C_x = \frac{\sum_{i=1}^{N} C_x(p_m) - C_x(p_i)}{max \sum_{i=1}^{N} C_x(p_m) - C_x(p_i)} \qquad \ldots (6)$$

We first tested whether Crisis and recession decreased centralization in the regional innovation network, and subsequently, whether including centralization in equation 1 reduced the effect size of Crisis and recession on regional exploration.

$$Centralization_{i\,t} = \beta_0 + \beta_1 Shock_{i\,t-2} + \alpha Z + \varepsilon_{it} \qquad \ldots (7)$$

$$Exploration_{i\,t+1} = \beta_0 + \beta_1 Shock_{i\,t-2} + \beta_5 Centralization_{i\,t} + \alpha Z + \varepsilon_{it} \qquad \ldots (8)$$

Insert Table 10 about here
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[7] The notion of centralization relates, but is different from, the construct of core periphery. A highly centralized network has a core-periphery structure.

Table 10 presents the analyses. Model 14 shows a positive and significant effect of the HPI (coefficient: 0.0375; p= 0.002) on degree centralization in the regional innovation network. Thus, Crisis and recession decreased hierarchy in the regional network. In Model 15, we included centralization in the equation, which has a significant negative effect (coefficient: -0.0744; p= 0.000) on regional exploration. Further, the effect-size of HPI on regional exploration was increased to -0.0675 (p= 0.000) from -0.0703 (p=0.000) in Model 2. Table 11 presents the results of Sobel-Goodman mediation analysis. We observe that Crisis and recession had a relatively small mediated effect (4.06% of total effect) on exploration by affecting the structural characteristics of regional knowledge-network. Coefficients of the direct and the indirect effects are respectively -0.0675 (p: 0.000) and -.0028 (p= 0.014).

Insert Table 11 about here
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6. Discussion and conclusions

This study reveals at least one potential upside of economic crises! It takes an empirical approach to understand how economic crises and recessions trigger distant search processes and exploratory learning in regions. Exploration is efficient in long run (March, 1991) – this is how a region creates technological diversity and specialization in emerging technologies. Contributing to region's dynamic adaptability, exploration makes regions resilient to future shocks. In this sense, our work resonates with the scholars who conceptualize resilience in terms of "bouncing forward" and creation of new efficient specialization lock-ins along adapted trajectories rather than "bouncing back" to the old ones (Boschma, 2015; Martin & Sunley, 2015).

Evidence related to mediating mechanisms extends our knowledge about crises and recessions. Previous research suggests that the resourceful innovator firms tend to "invest their way out of crisis". They indeed increase their R&D expenditure during downturns, which normally improves their performance (Archibugi, Filippetti, & Frenz, 2013; Aghion, Berman, Eymard, Askenazy, & Cette, 2012; Aghion & Saint-Paul, 1998; Amore, 2015; Flammer & Ioannou, 2018). However, positive effect of the concentration of resourceful firms in regional innovation during crises and recessions on regional exploration suggest that indeed these firms actively engage in distant search processes. Thus, crises press firms to commit to and produce new technologies – and as Bloom (2014) argues, create growth options and place bets on the technologies of future. In this sense, our paper also contributes to the literature on strategy.

Another mechanism which found empirical support, albeit with low effect size, was the decrease in hierarchy in regional innovation network. One possible reason can be termination of existing exploitation related projects in core technology areas, to which inventors of high centrality would normally belong. Secondly, firms' strategic emphasis on growth options and support to bottom-up projects may lead to creation of new ties between the non-central inventors. Most importantly, our study empirically establishes a relationship between hierarchy, which is a structural factor, and regional exploration, which is an innovation outcome (Carnabuci & Operti, 2013; Fang, Lee, & Schilling, 2010; Fleming et al, 2007; Keum & See 2016; Lazer & Friedman, 2007), when the hierarchy itself is changing temporally due to an exogenous factor. Thus, we respond to scholars calling for research on network dynamics (Ahuja, Soda & Zaheer, 2012; Brenner, Cantner, & Graf, 2013).

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FIGURES AND TABLES

Table 1. List of Variables, their Operationalization and Data-sources

Constructs	Operationalization	Data-sources
Unit of analysis		
Region	Metropolitan Statistical Area (MSA), in the USA	NLSY Geocode Codebook supplement (9)
Dependent variable		
Regional exploration	A patented invention denotes a case of exploration if it is assigned a main-class, in which no other patent from the MSA was assigned in the last ten years.	USPTO (US Patent Classification data)
Independent variable		
Economic crisis & recession (main equation)	Changes in housing price index in MSA. HPI (non-seasonally adjusted; average of all quarters). Lower the index, higher the intensity of crisis & recession.	Federal Housing Finance Agency
Economic crisis & recession (for robustness analysis)	Per capita GDP (chained 2009 US Dollars) in the MSA. Lower the GDP, higher the intensity of crisis & recession.	US Bureau of Economic Analysis (regional data)
Control variables		
Region's intellectual resourcefulness	Natural log of the size (number of nodes/inventors) of MSA's co-patenting network	USPTO: Patent-inventor-location
Connectedness of inventors in region	Percentage of nodes (inventors) forming largest connected component in MSA's co-patenting network	USPTO: Patent-inventor-location
Density of inventors' collaboration in region	Average degree of each node (inventor) in MSA's co-patenting network	USPTO: Patent-inventor-location
Outward orientation of regional inventors	Ratio of total number of external collaboration ties over total number of internal ties, formed by inventors in MSA	USPTO: Patent-inventor-location
Technological concentration in patenting	Herfindahl index (HHI) of patenting in the MSA by USPC technology main classes	USPTO: Patent-inventor-location-classification

Relative size of high-technology sector	Natural log of the number of employees in high-tech industries out of the total number of employees in the MSA	US Bureau of Economic Analysis (regional data)
Quality of human capital in high-tech	Per capita annual payment in the high-tech sectors in the MSA	US Bureau of Economic Analysis (regional data)
Policy support to higher education	Per capita expenditure on higher education at the state level	US Census Bureau: State and Local Government Finance (state data)
Technology main-class assignment FE	Number of patents filed by inventors from the MSA in each USPC main-class (up to 2 digits) in the given application year	USPTO: US Patent classification at time of issue; inventor-region
Year FE	Application year of patent-filing	USPTO: US Patent application date
For test of mechanisms		
Newness of inventors in the region	Mean experience of the junior-most co-inventors of all patents filed from the MSA.	USPTO: Patent-inventor-location
Entrant assignees in the region	Share of patenting done by the first-time assignees in the MSA.	USPTO: Patent-assignee-location
Hierarchy in region's innovation network	Degree-centralization of MSA's co-patenting network of inventors	USPTO: Patent-inventor-location
Dominance of resourceful innovators	Herfindahl index (HHI) of patenting in the MSA by assignee organizations.	USPTO: Patent-assignee-location

Table 2. Descriptive Analysis (Variables and their distribution)

Variable	Observations	Mean	Std. Dev.	Min	Max
Share of exploration	7,426	0.141	0.184	0	1
Housing Price Index	7,023	169.087	36.492	86.714	364.25
Per capita GDP (MSA)	6,576	4.165	1.223	1.586	17.831
Network size (log)	6,146	5.264	1.798	0	10.356
Share - largest component	6,146	0.118	0.103	0.008	1
Average degree	6,146	1.363	1.010	0	5.844
Outward orientation	6,802	6.031	10.600	0	229
HHI – USPC main class	7,418	0.198	0.238	0.026	1

Employment in high-tech (log)	6,355	9.219	1.571	3.689	13.949
PC salaries in high-tech	6,355	49.732	15.091	13.975	165.953
PC state-funding to higher ed.	5,707	0.680	0.375	0	8.119
Newness of inventors*	7,426	6.217	8.307	1	270.333
Entrant assignees*	5,443	0.294	0.208	0.011	1
Network hierarchy*	6,144	0.042	3252.331	1	31432
HHI – assignees*	7,378	0.165	0.180	0.004	1

*In the test of mechanism

Table 3. Correlation Matrix of independent and control variable [after Panel Regression (Fixed Effects) Model]

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Housing Price Index	1												
2	Network size (log)	-.075	1											
3	Share - largest component	.043	.019	1										
4	Average degree	.024	-.447	-.401	1									
5	Outward orientation	-.021	.026	-.001	.074	1								
6	HHI – USPC main class	-.067	.106	-.005	-.038	-.043	1							
7	Employment in high-tech (log)	.010	-.014	-.009	.010	.010	-.004	1						
8	PC salaries in high-tech	-.078	-.013	.039	-.012	.014	.026	-.107	1					
9	PC state-funding to higher ed.	.005	-.026	-.001	.024	-.000	-.000	-.004	-.023	1				
10	Newness of inventors*	.007	-.013	-.021	-.014	-.044	-.023	.006	.018	-.016	1			
11	Entrant assignees*	-.015	.088	.024	-.011	.030	-.029	-.013	.020	.000	.059	1		
12	Network hierarchy*	-.047	.234	-.330	-.300	.029	.024	.013	-.004	-.009	.001	.064	1	
13	HHI – assignees*	.011	.057	-.165	-.024	-.018	-.123	-.047	.008	-.021	-.127	.152	.058	1

Table 4. Effects of Economic Crisis on Regional Exploration

VARIABLES	Model 1 FE Panel regression Regional exploration	Model 2 FE Panel regression Regional exploration	Model 3 FE Panel regression Regional exploration
Housing Price Index		-0.0703***	
		(0.0146)	
Per capita GDP (MSA)			-0.0698*
			(0.0333)
Network size (log)	-0.5228***	-0.4841***	-0.5184***
	(0.1084)	(0.1084)	(0.1084)
Share - largest component	0.0072	-0.0111	-0.0075
	(0.0224)	(0.0223)	(0.0223)
Average degree	-0.0020	-0.0048	-0.0024
	(0.0365)	(0.0364)	(0.0365)
Outward orientation	0.0081	0.0092	0.0081
	(0.0094)	(0.0094)	(0.0094)
HHI – USPC main class	-0.0164	-0.0094	-0.0157
	(0.0235)	(0.0234)	(0.0235)
Employment in high-tech (log)	0.0442	0.0420	0.0465
	(0.0327)	(0.0326)	(0.0327)
PC salaries in high-tech	0.0870***	0.0952***	0.0901***
	(0.0232)	(0.0232)	(0.0232)
PC state-funding to higher ed.	0.0113	0.0109	0.0120
	(0.0100)	(0.0099)	(0.0100)
USPC Main class FE	YES	YES	YES
Application year FE	YES	YES	YES
Constant	0.2284**	0.1526***	0.2236***
	(0.0427)	(0.0454)	(0.0427)
Observations	4,487	4,487	4,487
R-squared	0.2542	0.2586	0.2550
Number of MSAstate	435	435	435

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

Table 5. Difference-in-difference: Effect of Economic Crisis on Regional Exploration

VARIABLES	Model 4 FE Panel regression Regional exploration	Model 5 FE Panel regression Regional exploration
1.Crisis (2011-14)	-0.8238***	-0.8871***
	(0.0631)	(0.0649)
1.Hit		(Omitted)

1.Crisis (2011-14) # 1.Hit		0.1282***
		(0.0317)
Network size (log)	-0.5228***	-0.5219***
	(0.1084)	(0.1082)
Share - largest component	-0.0072	-0.0087
	(0.0224)	(0.0223)
Average degree	-0.0020	-0.0011
	(0.0365)	(0.0364)
Outward orientation	0.0081	0.0088
	(0.0094)	(0.0094)
HHI – USPC main class	-0.0164	-0.0156
	(0.0235)	(0.0234)
Employment in high-tech (log)	0.0442	0.0514
	(0.0327)	(0.0326)
PC salaries in high-tech	0.0870***	0.0897***
	(0.0232)	(0.0231)
PC state-funding to higher ed.	0.0113	0.0116
	(0.0100)	(0.0100)
USPC Main class FE	YES	YES
Application year FE	YES	YES
Constant	0.2284***	0.2253***
	(0.0427)	(0.0426)
Observations	4,487	4,487
R-squared	0.2542	0.2573
Number of MSAstate	435	435

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

Table 6. Effects of concentration of patenting by assignee firms during Crisis on regional exploration

	Model 6	Model 7	Model 8	Model 9
VARIABLES	FE panel regression			
	Regional exploration			
Crisis years	**2007**	**2008**	**2009**	**2007-2012**
HHI assignees	-0.0971***	-0.0860***	-0.0855***	-0.0932***
	(0.0200)	(0.0198)	(0.0199)	(0.0207)
1.crisis	-0.0784^	-0.1407**	-0.2671***	-0.7851***
	(0.0421)	(0.0431)	(0.0443)	(0.0477)
1.crisis # c.HHI assignee	0.1831***	0.1858***	0.1038*	0.0413^
	(0.0351)	(0.0418)	(0.0422)	(0.0218)
Network size	-0.5427***	-0.5289***	-0.5381***	-0.5274***

	(0.1074)	(0.1075)	(0.1077)	(0.1080)
Share - largest component	0.0035	0.0015	0.0043	0.0049
	(0.0225)	(0.0225)	(0.0226)	(0.0226)
Average degree	-0.0000	0.0006	0.0013	-0.0011
	(0.0361)	(0.0361)	(0.0362)	(0.0362)
Outward orientation	0.0080	0.0078	0.0085	0.0079
	(0.0093)	(0.0093)	(0.0094)	(0.0094)
HHI – USPC main class	0.0117	0.0086	0.0104	0.0072
	(0.0236)	(0.0237)	(0.0237)	(0.0237)
Employment in high-tech (log)	0.0521	0.0516	0.0515	0.0524
	(0.0324)	(0.0324)	(0.0324)	(0.0325)
PC salaries in high-tech	0.0862***	0.0837***	0.0874***	0.0865***
	(0.0229)	(0.0230)	(0.0230)	(0.0230)
PC state-funding to higher ed.	0.0122	0.0121	0.0118	0.0123
	(0.0099)	(0.0099)	(0.0099)	(0.0099)
USPC Main class FE	YES	0.0004	0.0001	0.0001
Application year FE	YES	(0.0016)	(0.0016)	(0.0016)
Constant	0.2269***	0.2265***	0.2269***	0.2227***
	(0.0424)	(0.0424)	(0.0425)	(0.0426)
Observations	4,483	4,483	4,483	4,483
R-squared	0.2641	0.2627	0.2602	0.2597
Number of MSAstate	435	435	435	435

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

Table 7. Effects of Economic Crisis on HHI of assignees and regional exploration

VARIABLES	Model 10 FE Panel regression HHI assignees*Crisis year (2007)	Model 11 FE Panel regression Regional exploration
Housing Price Index	-0.1269***	-0.0636***
	(0.0219)	(0.0145)
HHI assignees*Crisis year (2007)		0.0506***
		(0.0105)
HHI assignees	0.2658***	-0.0958***
	(0.0299)	(0.0200)
Network size (log)	0.0851	-0.5076***
	(0.1628)	(0.1074)

Share - largest component	0.0117***	-0.0001
	(0.0341)	(0.0225)
Average degree	-0.0105***	-0.0025
	(0.0546)	(0.0360)
Outward orientation	0.0062	0.0090
	(0.0141)	(0.0093)
HHI – USPC main class	-0.0277	0.0176
	(0.0358)	(0.0236)
Employment in high-tech (log)	-0.0265	0.0500
	(0.0489)	(0.0323)
PC salaries in high-tech	-0.0298	0.0938***
	(0.0348)	(0.0229)
PC state-funding to higher ed.	0.0028	0.0118
	(0.0149)	(0.0098)
USPC Main class FE	YES	YES
Application year FE	YES	YES
Constant	1.3698	0.2142
	(0.9633)	(0.6298)
Observations	4,483	4,483
R-squared	0.5677	0.6881
Number of MSAstate	435	435

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

TABLE 8: Sobel-Goodman Mediation Analysis – HHI assignees in regional innovation during Crisis

	Coefficient	**Std. Error**	**Z**	**P<|Z|**
Sobel	-.0064164	.00173455	-3.699	.0002163
Goodman-1 (Aroian)	-.0064164	.00174977	-3.667	.00024542
Goodman-2	-.0064164	.00171919	-3.732q	.0001898
a coefficient	-.126881	.021866	-5.80267	6.5e-09
b coefficient	.05057	.010533	4.80129	1.6e-06
Indirect effect	-.006416	.001735	-3.69917	.000216
Direct effect	-.063577	.014492	-4.38696	.000011
Total effect	-.069993	.014471	-4.83681	1.3e-06

Proportion of the total effect that is mediated:	.09167175
Ratio of indirect to direct effect:	.10092359
Ratio of total to direct effect:	1.1009236

Table 9. Effects of Economic Crisis on entry of inventors and ventures

VARIABLES	Model 12 FE Panel regression Newness of inventors	Model 13 FE Panel regression Entrepreneurial entry
Housing Price Index	0.0067	0.0152
	(0.0173)	(0.0175)
Network size (log)	0.0831	-0.5372***
	(0.1287)	(0.1341)
Share - largest component	0.0706**	-0.1265***
	(0.0266)	(0.0277)
Average degree	0.0353	-0.0316
	(0.0433)	(0.0446)
Outward orientation	0.0312**	-0.0229*
	(0.0112)	(0.0108)
HHI – USPC main class	0.0464^	0.0149
	(0.0277)	(0.0280)
Employment in high-tech (log)	0.0040	0.0153
	(0.0388)	(0.0389)
PC salaries in high-tech	-0.0317	-0.0323
	(0.0276)	(0.0277)
PC state-funding to higher ed.	0.0138	-0.0037
	(0.0118)	(0.0114)
USPC Main class FE	YES	YES
Application year FE	YES	YES
Constant	-0.1188*	0.2390***
	(0.0538)	(0.0481)
Observations	4,498	4,113
R-squared	0.0761	0.0859
Number of MSAstate	435	434

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

Table 10. Effects of Economic Crisis on network hierarchy and regional exploration

VARIABLES	Model 14 FE Panel regression Degree centralization	Model 15 FE Panel regression Regional exploration
Housing Price Index	0.0375**	-0.0675***
	(0.0121)	(0.0146)
Degree centralization		-0.0744***
		(0.0191)
Network size (log)	-1.2784***	-0.5800***

	(0.0901)	(0.1109)
Share - largest component	0.4163***	0.0198
	(0.0186)	(0.0236)
Average degree	0.5847***	0.0388
	(0.0303)	(0.0380)
Outward orientation	-0.0151^	0.0080
	(0.0078)	(0.0094)
HHI – USPC main class	-0.0541**	-0.0135
	(0.0194)	(0.0234)
Employment in high-tech (log)	-0.0320	0.0397
	(0.0272)	(0.0325)
PC salaries in high-tech	-0.0016	0.0951***
	(0.0193)	(0.0231)
PC state-funding to higher ed.	0.0029	0.0111
	(0.0083)	(0.0099)
USPC Main class FE	YES	YES
Application year FE	YES	YES
Constant	0.1111**	0.1611 ***
	(0.0377)	(0.0454)
Observations	4,498	4,487
R-squared	0.3573	0.2614
Number of MSAstate	435	435

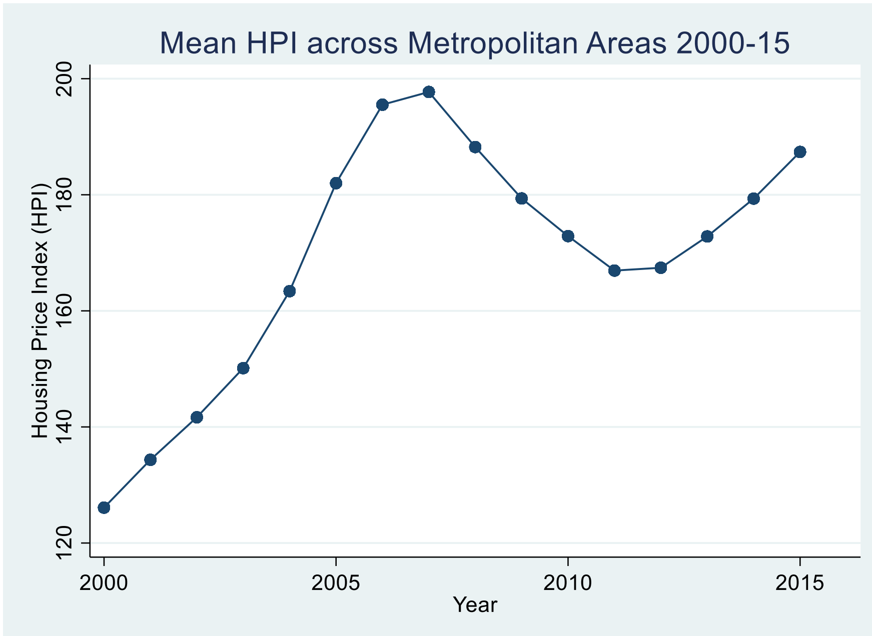
Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

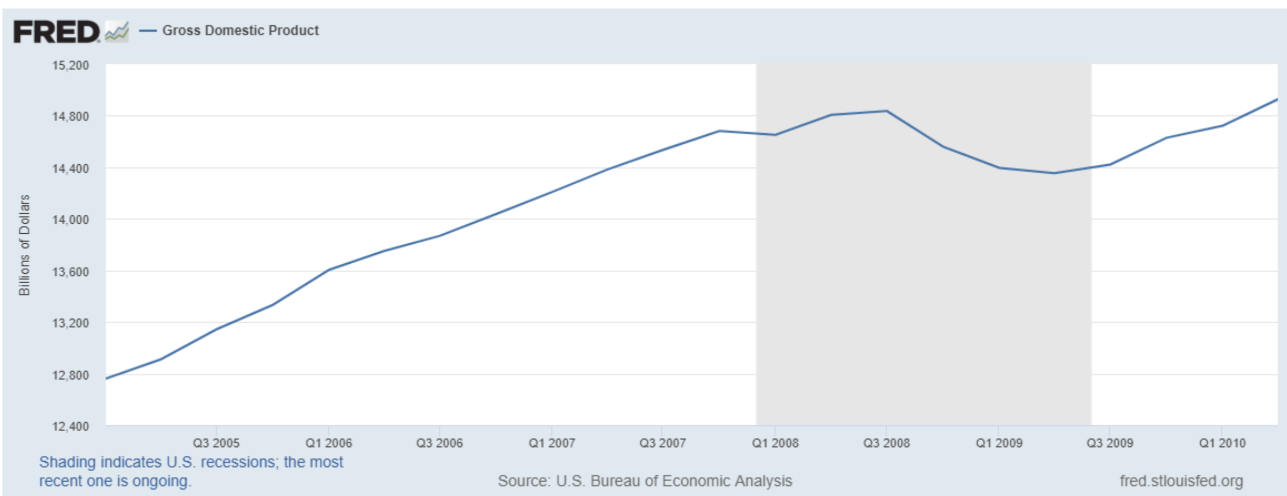
TABLE 11: Sobel-Goodman Mediation Analysis – Degree-centralization (Hierarchy) in Regional Innovation Network

	Coefficient	**Std. Error**	**Z**	**P<|Z|**
Sobel	-.00285789	.00116378	-2.413	.01583169
Goodman-1 (Aroian)	-.00285789	.00118666	-2.365	.01801967
Goodman-2	-.00285789	.00114044	-2.463	.01376566
a coefficient	.038426	.012148	3.16313	.001561
b coefficient	-.074374	.01909	-3.89605	.000098
Indirect effect	-.002858	.001164	-2.45569	.014061
Direct effect	-.067471	.014558	-4.63458	3.6e-06
Total effect	-.070329	.014566	-4.82834	1.4e-06

Proportion of the total effect that is mediated:	.04063601
Ratio of indirect to direct effect:	.04235724
Ratio of total to direct effect:	1.0423572

Figure 1. Movement of Housing Price Index (mean across MSAs) and US GDP





Source: FRED Economic Data – US GDP. Available on https://fred.stlouisfed.org/series/GDP