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Technological Diversification of Cities in Times of Crisis

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Abstract

Disclaimer: The article subject and goal changed significantly in the last few weeks prior to the due date for the 2016 DRUID conference in Bordeaux. This is due to the fact that the previous envisioned project prove to be unrealistic to pursue within the given time frame. The work presented here is very preliminary. The work here does not ascertain a full and correct representation of the literature on the subject and other related subjects. Nor has the methodology fully been developed. At this stage not even all authors have had the possibility to give their opinion on the work presented here. This paper must be read as a general direction of the research pursued and the methodology to be used. Please do not cite or circulate this work. There is a lot of controversy on the innovation behaviour at the national and regional level during crises. Where some ascertain that crises lead to less innovation behaviour others argue that recessions are a fertile environment to innovate (Filippetti & Archibugi , 2011). Schumpeter (1939) wrote an influential concept of creative destruction in relation to Kondratiev (1925) waves supporting the latter view. Related to the Oil Crisis Mensch (1975) elaborated on this by developing the so-called depression trigger theory. This was however countered by Clark, Freeman & Soete (1981) and Van Duijn (1983) who claimed that most innovations were in fact just made after the crisis ended. A theory proposed by Kleinknecht (1981) manages to make both compatible: He claims that during the crisis more radical innovation takes place but that most innovation in quantitative terms happens during the period of growth following the crisis. However the data used by these authors consists of innovations identified by hand. Leading to a fair share of criticism. After the beginning of the crisis in 2008 the Schumpeterian idea of creative destruction found its way into a new emerging concept: regional resilience. Martin (2012) identifies the region as the relevant spatial level. Diversification, a Schumpeterian idea related to the development of new growth paths, becomes a key element in regional resilience (Boschma, 2015). It is reasoned that this concept of adaptability among others speeds up recovery during crises (Neffke, Henning & Boschma, 2011; Martin, 2012; Boschma, 2015). The ideas behind this are related to the ones in the long wave literature. However evidence is drawn from relatively few case-studies. Which does not give full conclusive evidence if regions actually diversify during every crisis. The issue until recently however was that it was impossible to do a systematic analysis of multiple regions due to the highly qualitative and path dependent nature of diversification. This article builds on two developments to look into diversification during crises. First, building on the network of relatedness firstly developed by Hidalgo, Klinger, Barabasi & Hausmann (2007) it is possible to quantify the relatedness of new technologies patented in a region in relation to the technologies a region was already specialized in. Second, a collaboration between Google and the U.S. Patent and Trademark Office (USPTO) led to the online availability of all patents registered by the USPTO since 1836. Giving massive data availability on technological development during the greatest crises of U.S. history. Using an entry model based on Boschma, Balland & Kogler (2015) it is checked if more related or unrelated technologies enter the portfolio of a region during these great crises. The crises retained are: the Civil War, the Long Depression, the First World War, the Great Depression, the Second World War and the Gulf Crisis. The research is at a very preliminary stage but first results seem to confirm the idea of Kleinknecht (1981). Less new technologies enter the portfolio of a region during crises compared to periods of growth. However the technologies that do enter are more radical during crises. It is also shown that this does not go for every crisis. While war-related crisis do not show this behaviour. Further elaboration of this research will hopefully explain this.

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Abstract (662 out of 1000 words)

There is a lot of controversy on the innovation behaviour at the national and regional level during crises. Where some ascertain that crises lead to less innovation behaviour others argue that recessions are a fertile environment to innovate (Filippetti & Archibugi , 2011). Schumpeter (1939) wrote an influential concept of creative destruction in relation to Kondratiev (1925) waves supporting the latter view. Related to the Oil Crisis Mensch (1975) elaborated on this by developing the so-called depression trigger theory. This was however countered by Clark, Freeman & Soete (1981) and Van Duijn (1983) who claimed that most innovations were in fact just made after the crisis ended. A theory proposed by Kleinknecht (1981) manages to make both compatible: He claims that during the crisis more radical innovation takes place but that most innovation in quantitative terms happens during the period of growth following the crisis. However the data used by these authors consists of innovations identified by hand. Leading to a fair share of criticism.

After the beginning of the crisis in 2008 the Schumpeterian idea of creative destruction found its way into a new emerging concept: regional resilience. Martin (2012) identifies the region as the relevant spatial level. Diversification, a Schumpeterian idea related to the development of new growth paths, becomes a key element in regional resilience (Boschma, 2015). It is reasoned that this concept of adaptability among others speeds up recovery during crises (Neffke, Henning & Boschma, 2011; Martin, 2012; Boschma, 2015). The ideas behind this are related to the ones in the long wave literature. However evidence is drawn from relatively few case-studies. Which does not give full conclusive evidence if regions actually diversify during every crisis. The issue until recently however was that it was impossible to do a systematic analysis of multiple regions due to the highly qualitative and path dependent nature of diversification.

This article builds on two developments to look into diversification during crises. First, building on the network of relatedness firstly developed by Hidalgo, Klinger, Barabasi & Hausmann (2007) it is possible to quantify the relatedness of new technologies patented in a region in relation to the technologies a region was already specialized in. Second, a collaboration between Google and the U.S. Patent and Trademark Office (USPTO) led to the online availability of all patents registered by the USPTO since 1836. Giving massive data availability on technological development during the greatest crises of U.S. history.

Using an entry model based on Boschma, Balland & Kogler (2015) it is checked if more related or unrelated technologies enter the portfolio of a region during these great crises. The crises retained are: the Civil War, the Long Depression, the First World War, the Great Depression, the Second World War and the Gulf Crisis. The research is at a very preliminary stage but first results seem to confirm the idea of Kleinknecht (1981). Less new technologies enter the portfolio of a region during crises compared to periods of growth. However the technologies that do enter are more radical during crises. It is also shown that this does not go for every crisis. While war-related crisis do not show this behaviour. Further elaboration of this research will hopefully explain this.

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Technological Diversification of Cities in Times of Crisis

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Introduction

The main question of this article is straight forward and seemingly simple: "Do regions diversify in more related or unrelated activities during crises?" However the question is answered radically differently in different currents in crisis-related literature. "Concerning the relationship between innovation and business cycles, two extreme hypotheses can be outlined: according to the first, innovation is cyclical and therefore firms tend to reduce their innovation efforts during the downswing of the economy, while according to the second, it is instead counter-cyclical and claims that recessions are a fertile environment for firms to innovate." (Filippetti & Archibugi , 2011, p. 179)

An influential proponent of the latter view was Schumpeter (1939). He didn't use monetary or monetary-related explanations to business cycles witnessed in economic indicators by Kondratiev (1925) as was common at that time. Schumpeter (1939) instead popularized the link between these Kondratiev waves and innovation (Korotayev & Tsirel, 2010). The resulting Schumpeterian theory of creative destruction would attract new academic interest after every major crisis. A first wave of interest occurred after the oil crisis of the 70s among others Mensch (1975), van Duijn (1983) and Kleinknecht (1981; 1987) relaunched the debate on long economic cycles and innovation.

After the 2008 crisis another wave of interest developed in which the concept of regional resilience gained a lot of popularity (Martin, 2012). While in the previously mentioned literature the country was the level of focus. The fact that regions within a country reacted noticeably differently to a crisis fuelled the need for an approach at this spatial level (Martin, 2012). Schumpeter's creative destruction inspired an important concept within the regional resilience literature: Diversification. Which is the capacity of a region to develop new regional growth paths. It has been assumed to be a key aspect of regional resilience. It is reasoned that this concept, also known as adaptability, among others speeds up recovery during crises (Neffke, Henning & Boschma, 2011; Martin, 2012; Boschma, 2015).

The logic behind the need for diversification is relatively similar between the two strains of literature. Which can be boiled down to: That when at the lowest point one is open to the greatest change. However the proof presented in both strains of literature is limited. Mensch (1975), van Duijn (1983), Kleinknecht (1987) and Kleinknecht & van der Panne (2006) construct datasets by identifying by hand major innovations over long time periods. This data is fairly controversial especially because it is difficult to arbitrarily distinguish radical from incremental innovations and the exact year of innovation. On top of this data could only give the mentioned authors fifteen innovations per year at a maximum to base their ideas and argumentation on. In the regional resilience literature systematic on the other hand statistical research on the topic has been avoided altogether so far. Pike et al. (2010), Neffke et al. (2011), Martin (2012) & Boschma (2015) only cite a few and fairly recent case-studies in which regions managed to overcome crises by diversifying into new growth paths. This hardly gives conclusive evidence and even Martin (2012) & Boschma (2015) selves agree more research is needed.

There are two issues that until recently stood in the way of performing a more quantitative research over a long time period on the subject: data availability and the highly qualitative nature of the topic of diversification. For the latter issue the seminal work of Hidalgo, Klinger, Barabasi & Hausmann (2007) brought an answer. Based on co-occurrences of product specializations they manage to create a network of relatedness. Neffke et al. (2011) build upon this framework using industries at the regional level to quantify diversification. Boschma, Balland & Kogler (2015) and Balland, Rigby & Boschma (2015) successfully apply it on patent data. The break-through on the data side came to being due to a collaboration between Google and the U.S. Patent and Trademark Office (USPTO). Which led to the online availability of all patents registered by the USPTO since 1836.

The incredible wealth of this data makes it possible to look into all the great crises that inspired many famous economists to start writing on business cycles. In this preliminary version of work the focus lies on the diversification behaviour of Metropolitan Statistical Areas (MSAs) during the greatest crises in U.S. history: the Civil War, the Long Depression, the First World War, the Great Depression, the Second World War and the Gulf Crisis. The crises that are not related to war coincide very well with the downswing phases of the Kondratiev waves. For the World Wars this is only true according to certain views of the Kondratiev waves. In the case of the Civil War it is clear that it does not coincide with a downswing phase. In this research all these crises are evaluated but it is envisioned to also look at smaller and local crises in a future stage of the research.

To see if the regions diversify more radically during these large crises a so-called entry model based upon the one used by Boshma et al. (2015) is used. This is a discrete model in which the dependent variable is a dummy for the appearance or not of a certain technology in the portfolio of a certain region at a certain time period. The time periods are defined as regional crises following the shock of great crises mentioned before and the periods of growth outside of these crises. The explanatory variable of most interest is the importance of the relatedness with the technological portfolio of the newly technologies times a crisis dummy variable. The coefficient on this interaction variable shows that during crises the relatedness of entering technologies is lower. Showing that during crises more radical innovations are made. However when this is evaluated for only the war related crises the degree of relatedness does not change significantly. Why this is will be explained in a future stage of the research.

First the literature on the respectively long wave (1.) and regional resilience (2.) is reviewed. After which in part 3 the data and the methodology is presented. In 4. the first results are presented and briefly discussed.

1. Long wave literature

Although many cycles exist[1] the focus in this paper at this stage is on the Kondratiev waves. Kondratiev explained the dynamics he observed on the basis of capital investment dynamics. But he did notice that it seemed that during the downswing periods of the waves an especially large number of important inventions were made (Kondratiev, 1925 *in* Korotayev & Tsirel, 2010). Schumpeter (1939) followed this line of reasoning to come to a theory which stated that "*In order to produce fluctuations which are visible in macroeconomic data, radical innovations should not be randomly distributed over time but should come about in clusters or waves*" (Kleinknecht, 1987, p. 81).

More precisely in his theory of creative destruction this swarming of innovations takes place in the downswing period of the wave. In accordance Mensch (1975) developed the depression-trigger hypothesis to explain the urge for radical innovation during crises. Clark, Freeman & Soete (1981) and Van Duijn (1983) however find that most innovation take place just after the crisis during the upswing of a wave. Clark et al. (1981) state that Mensch looks at the wrong swarming of innovation. These views are however not incompatible Kleinknecht (1981, p. 295) explains: "The argument that depression is acting as a trigger for major innovations … does not exclude the existence of a swarm of related innovations which accompany the diffusion of newly introduced products."

The theoretical explanation Kleinknecht (1981, p. 294) offers is that: "It may be that the profit maximization strategy of firms during prosperity periods will change into a strategy of minimizing risks, losses and uncertainties during long periods of economic distress. From this point of view, the argument that radical innovation projects are not started in times of crises and recession, when risks and uncertainties are highest, seems plausible. But it may be asked whether this argument does not backfire when looking at the relative risks and uncertainties of investment alternatives: innovation processes are generally of a risky nature. This risk is certainly lower in prosperous times-but so may be the incentive to innovate. Why should an enterprise deal with the uncertainties, risks and costs of introducing completely new products into the market, as long as its established products can be easily sold? Does not the firm make money much more easily and with less risk by restricting R and D activity to the mere improvement of existing products? The logical conclusion from this is that prosperous times are good times for quality augmenting and cost reducing improvement and process innovations, but they are bad times for radical innovators. Thus not only the risks but also the incentives for radical innovations could considerably increase in periods of distress. There may be decreasing returns to R and D expenditures for further improvements of mature products. Moreover, demand saturation for individual products, as well as a general decline of demand due to the crisis, may lead to overcapacity in existing product lines. In this situation, further expansionary investments become risky, if not disastrous. As to investment and R and D strategy, there remain only two reasonable alternatives: firms may try to cope with sharper price competition for their old products, by means of rationalization investment; or they may try to open up completely new investment areas by innovating radically new products."

If this last strategy is followed and is successful other firms may join which will lead to a large stream of additional innovations. This is called the bandwagon effect. This latter effect would be the swarming effect noticed by Clark et al. (1981) and van Duijn (1983). Proof for the reasoning of Kleinknecht has been found by Archibugi, Filippetti & Frenz (2012) who analyzed the financial crisis of 2008.

[1] Well-known other examples are the Kitchin (1923), Juglar (1862) and Kuznetz (1930) cycles.

However the proof for the historic crises has been heavily debated. Especially the data used for this type of research has met with scepticism. Kleinknecht (1987, p. 87) names the following problems: "*the representativeness of sources, the randomness of selection principles, the distinction between 'major' and 'minor' events, appropriate sample size, or the determination of innovation years.*" See Clark et al. (1981) for further elaboration on this. The patent data used in this article spans between 1836 and 2002[2]. Which gives plenty of opportunity to test when exactly the more radical innovations are made. As explained in the data part.

2. Regional resilience literature

One could say that interest in the Schumpeterian process of creative destruction is also cyclical because in the years following the financial crisis of 2008 attention has increased for the concept of regional resilience (Martin, 2012). The reason for the use of a finer spatial scale is the great disparity in how regional economic indicators reacted to the financial crisis even within a country (Martin, 2012).

In regional resilience many authors (Pike et al., 2010; Martin, 2012; Boschma, 2015) refute the 'engineering' type of resilience. According to them regional resilience is not just this ability of regions to accommodate shocks but also the long-term ability of regions to develop new growth paths, known as diversification or adaptability. In this conceptualization history and geography and thus path dependency is a key input (Boschma, 2015).

Pike et al. (2010), Neffke et al. (2011), Martin (2012) & Boschma (2015) see in diversifying into new growth paths a way to prevent a negative lock-in. However each of the authors can only cite a few case-studies. Mostly cited is work by Glaeser (2005) on how Boston manages to develop on new but skill-related growth paths, work by Grabher (1993) on the failure of the Ruhr-area in Germany to move away from its' coal and steel industry and a more general work on the shift from mass-production to more flexible industrial systems by Scott (1988). Pike et al. (2010) cite some more examples ranging from European countries to the auto- and steel-dominated regions in the USA.

The theoretical explanation of why exactly during crises regions will diversify can be found in these case-studies. Grabher (1993, p. 257) states that a crisis cannot only be explained from the demand side because it does not explain "why regional redeployment of the productive resources that were set free by the decreases in demand did not occur." Glaeser (2005, p. 151) adds to this "Diversity means that when the dominant industry suffers, producers from competing sectors expand and innovate, taking advantage of the decline in wages and the cost of capital."

This is clearly distinctive from the depression-trigger hypothesis but definitely compatible. If we take from the reasoning of Kleinknecht that the incentive for radical inventions increase because there are decreasing returns in R&D in maturing products. This incentive can be even stronger if the productive resources are set free leading to declining wage and capital costs like suggested by Grabher and Glaeser. On the other hand banks are less likely to lend out money in these periods. But it is not within the scope of this paper to find the theoretical explanation behind any diversification behaviour. Here it is only tested if and during crises more radical innovations are made.

[2] In the near future data it is hoped that workable patent data until 2010 is available. Because it takes time before a patent is granted patents that are filed in recent years may not have been granted yet. Which makes analyzing the recent crises currently impossible.

The regional resilience literature almost takes as given that the concept of adaptability is a way to prevent and come out of crises. However it is only based on a few case-studies. The fact is that these descriptive studies, most of them written for other purposes, mostly deliver only circumstantial evidence. This anecdotal evidence on a few cases hardly is conclusive to see to what extent regions diversify more during the crisis. The importance of diversifying could be over- or underestimated, there can be other factors at role and it could also be that the choice of the regions in the descriptive studies has an influence on the results. On top of that it is difficult to compare these studies. A more systematic research is of added value.

Martin (2012, p. 11) agrees that more research is needed he states: "How regional economies adapt over time, and why some regions appear more successful in this respect than others, are largely unresearched issues, but such adaptation is arguably a key source of economic resilience. Boschma (2015, p. 738) asks "whether regions can keep relying on recombinations between related industries (i.e. related diversification) to develop new growth paths in the long run, or whether regions have to diversify in more unrelated activities now and then, that is, making new combinations between unrelated domains that become related as soon as these domains connect."

This last quote shows that distinguishing different crises is important. In this preliminary version of the article only the great crises within time period of our data are analysed. It is the idea to add other crises in the near future.

The "*absence of large-scale statistical research is not surprising, given that the process of structural change is highly idiosyncratic and involves different industries in different regions. The qualitative nature of the phenomenon makes it difficult to compare the process of structural change in one region to one that occurred in another region in more quantitative terms*." (Neffke et al., 2011, p. 238) Doing research on diversification used to require a fine-tuned approach based on the specific region under investigation.

Neffke et al. (2011) however build on a seminal work by Hidalgo et al. (2007). Hidalgo et al. (2007) Use the exportations per product field of countries to calculate the relative specialization of these countries. Based upon the co-occurrence of these specializations the relatedness between these products can be calculated. The relatedness between products was depicted using a so-called product space. A network in which the nodes are product fields and the edges give the relatedness. Developing on this Neffke et al. (2011) construct an industry space and Boschma et al. (2015) and Balland et al. (2015) used the same framework to construct a technology space for patents. Which will be used here.

All these academics came to the conclusion that the relatedness network used shows that the capabilities present in a region or country conditions which new industries/products/technologies are developed and which successfully stay in a region. This behaviour however has not been researched yet in relation to crises nor over such a large time period. In this paper an adapted entry model based on the one in Boschma et al. (2015) is developed to look into this.

3. Data & Methodology

Following an agreement between the USPTO and Google the latter began to scan and convert to editable text all patents registered since 1836. Most patent information on inventors, technology classes & date can be obtained from related sources. The geographical location of the inventors and/or assignees cannot be obtained in such a direct manner. This was solved by using a data scraping algorithm to scan the online OCR-text of the patents for place names[3]. Based among others on the position in the text of this geographical location and the words in its vicinity the most likely geographical location is selected. A methodological paper by Petralia, Balland & Rigby (2015) on this process will be available in the near future. Until that time any questions on the topic can be mailed to the main author of this article.

Patent data holds a wealth of information. The dataset used here gives the opportunity to know exactly when, where, what was invented by who as far back as 1836. Not only is the invention explained in every patent but it is also classified by the USPTO using 441 primary technology classes and thousands of subclasses. The USPTO reclassifies technology classes of all patents when adjustments are made in the classification. Which makes that the classes are consistent over time and make for straightforward comparisons between innovations.

Despite of this richness of data there has also been a lot of critique on the "noisiness" of patent data. An important critique relevant to this work is that patent statistics cannot be seen as an "*an overall measure of economic and inventive activity, mainly because patented inventions do not represent all forms of knowledge production with an economy and thus certainly do not capture all produced knowledge.*" (Boschma et al., 2014, p. 228). It is important to keep in mind that patents although correlated with economic performance do not give a direct representation of the economic performance of a MSA. Also if a region diversifies in unpatentable activities this will not be captured by our methodology. However we believe this risk to be rather small.

Another important limitation is that the importance of each patented invention cannot directly be inferred. If we would use our dataset to find the major innovations we would have the same issues as Mensch, van Duijn & Kleinknecht to point out the major innovations and when exactly they made their impact. Kleinknecht (1987, p. 85) gives the example that "*one source is covering the first commercially successful steamship, while the other source takes the year of the first Atlantic crossing by a steamship*".

What however is possible is to pinpoint the moment and degree of technological change in patents issued (Boschma et al., 2015). When a new technology class makes its appearance in a MSA in a certain time period it is possible to calculate its relatedness to the technologies present in a MSA in the previous time period. As will be explained further on. When the time periods are defined on the basis of crises it can be verified when innovations are more radical and when more incremental.

It is then yet uncertain if these technologies will form the new boom in the wave. And even when it does it is probable to need some time before the technologies popularize. But evidence on the question if it is actually during crises that regions diversify can be delivered.

[3] Including historical place names.

Identifying crises

There are many economic indicators which one can use to identify crises. Unfortunately due to the spatial level and the time length of the data none are available on a year to year basis for our data. Patent data is highly correlated with economic performance (Glaeser & Ponzetto, 2007; Rothwell, Lobo, Strumsky & Muro, 2013) and the trend in number of patents gives an idea when a region is in crisis. It is however preferable to identify crises outside of the patent data to ascertain this link with economic performance. This is why in the first run it is chosen to use the great crises in the U.S.A. during our time period see *Table 1.*[4]

Event	Period
Civil War	1861-1865
The Long Depression	1873-1879
First World War	1917-1918
The Great Depression	1929-1934
Second World War	1942-1945
Gulf Crisis	1973-1975

Table 1. Crises and time periods

It is good to compare how these crises relate to the Kondratiev waves. There is a lot of discussion on how to exactly define the years of upswing and downswing. Korotayev & Tsirel (2010) made the following two tables in which common years used for the beginning and end of the Kondratiev waves are shown. The first table gives the waves as identified by Kondratiev himself. The second table is composed by Korotayev & Tsirel (2010) using various years proposed by academics following in the footsteps of Kondratiev

It can be clearly seen that the Civil War does not coincide with a downswing. For the First & Second World War it really depends. It seems that according to some definitions the entire period of the First World War, Great Depression and Second World War could be an entire period of down swing. There is in any case no doubt that The Long Depression, The Great Depression and the Gulf Crisis coincide with downswings in the Kondratiev waves. This research will nonetheless focus on all the crises mentioned although different models are tested excluding war-related crises and only taking into account the war-related crises. This will be described further on.

Long wave number	Long wave phase	Dates of the beginning	Dates of the end
One	A: Upswing	1787-1893	1810-1817
	B: Downswing	1810-1817	1844-1851
Two	A: Upswing	1844-1851	1870-1875
	B: Downswing	1870-1875	1890-1896
Three	A: Upswing	1890-1896	1914-1920
	B: Downswing	1914-1920	

Table 2. Kondratiev cycles as identified by Kondratiev (1925). Source: Korotayev & Tsirel (2010)

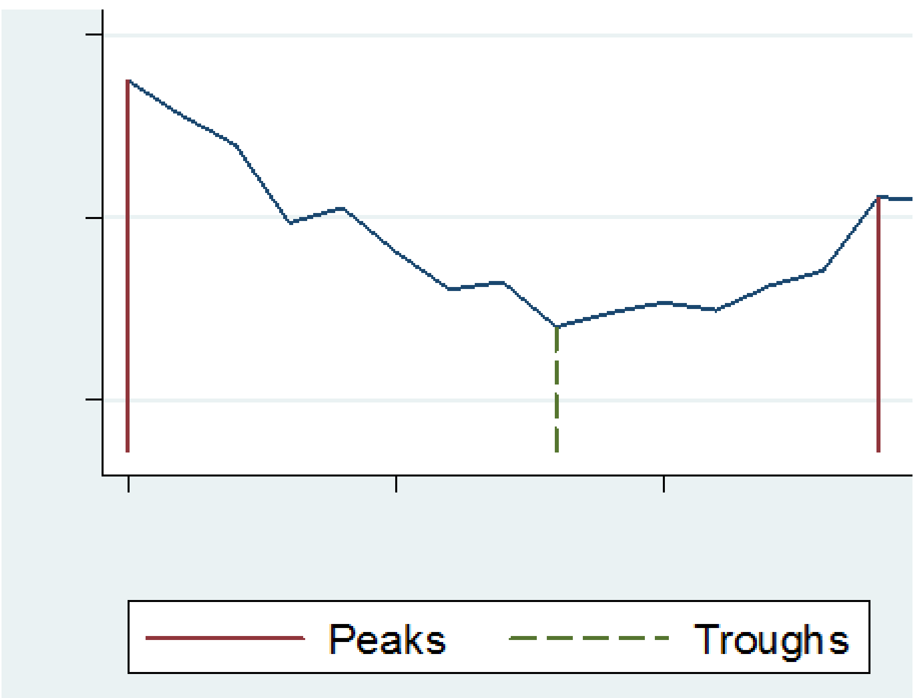
[4] Due to small time lags in patent data. The start and end years are slightly corrected to match the nation-wide crisis given here to the exact time periods in the patent data.

Long wave number	Long wave phase	Dates of the beginning	Dates of the end
Three	A: Upswing	1890-1896	1914-1920
	B: Downswing	From 1914-1928/1929	1939-1950
Four	A: Upswing	1939-1950	1968-1974
	B: Downswing	1968-1974	1984-1991
Five	A: Upswing	1984-1991	2008-2010(?)
	B: Downswing	2008-2010(?)	?

Table 3. Later Kondratiev cycles as identified by academics following the ideas of Kondratiev (1925). Source: Korotayev & Tsirel (2010)

To go from the national level to the MSA level each nationwide crisis is regarded as a shock at the regional level. A region can then either enter into a crisis as well or not. The crisis at the regional level is identified on the basis of the patent data using an adapted version of the business cycle algorithm by Harding & Pagan (2002) like has been done previously for patent data by Balland et al. (2015).

We follow the reasoning in Balland et al. (2015, p. 6) which states that technological crisis are defined "as sustained periods of negative growth in patenting activity. More formally, a time series recording yearly patenting activity can be defined as a continuum of local maxima (peaks) and minima (troughs) that divide the series into periods of technological growth from trough to peak and technological crisis from peak to trough." See Figure 1.



F*igure 1. Peak, trough, technological growth and technological crisis. Source: Balland et al. (2015)*

The algorithm[5] to detect business cycles "identifies potential turning points as the local minima (trough) and maxima (peak) in the series. Let's Pt be a patent count yearly series. A trough is identified as $(p_{t-j},\dots,p_{t-1}) > p_t^{trough} < (p_{t+j},\dots,p_{t+1})$ while a peak follows the condition that $(p_{t-j},\dots,p_{t-1}) < p_t^{peak} > (p_{t+j},\dots,p_{t+1})$." (Balland et al., 2015, p.) To prevent "noise" due to years of random growth or decline two extra conditions are imposed: "The phases (technological growth or technological crisis) should be at least 2 years long, while complete cycles (period between 2 peaks or between 2 troughs) should be at least 5 years long."

For every of the 367 metropolitan areas between 1836 and 2002 the periods of technological crisis and technological growth are identified. If a period of regional technological crisis starts during one of the great crises it is retained for the model. That these nation-wide crises do have considerable effect at the regional level can be seen in table 4. It shows the number of MSAs that enter in a crisis during one of the great nation-wide crises. Note that in certain time periods many MSAs did not exist yet.

Crisis	# of MSAs entering in crisis
Civil War	97
The Long Depression	140
First World War	208
The Great Depression	311
Second World War	257
The Gulf Crisis	330

Using an entry model it can be checked if technologies that enter during crises are more unrelated to the portfolio of a MSA than during periods of growth. For this relatedness needs to be measured

Measuring relatedness
Using the product space framework introduced by Hidalgo et al. (2007) mentioned before a technology space is build. Much like the one in Boschma et al. (2015) and Balland et al. (2015). The Revealed Comparative Advantage (RCA) given below is used to calculate in which technologies an MSA is relatively specialized in. In which x is the number of patents, c is the city-region and i is the primary technology class.

$$RCA(c,i) = \frac{\frac{x(c,i)}{\sum_i x(c,i)}}{\frac{\sum_c x(c,i)}{\sum_{i,c} x(c,i)}}$$

[5] The stata programme can be found here : http://fmwww.bc.edu/repec/bocode/s/sbbq.ado

Regions normally have a RCA in multiple primary technology classes. This co-occurrence in MSAs is used to establish the relatedness between the technologies. For each of the 441 primary technology classes it is evaluated if its number of co-occurrences with other classes is higher than what could be expected if the classes were randomly distributed. The formula used is based on the association index (Van Eck & Waltman, 2009). In which Cij is the co-occurrence between technology i and technology j, Si and Sj are the total number of times that I respectively j co-occurrs with another class and T is total number of co-occurences[6].

$$\frac{C_{ij} * T}{(S_i * S_j)}$$

For every time period this 441 by 441 relatedness matrix is calculated. Because every region experiences periods of crisis and growth in different time periods. Moving windows are used. Which means that the matrices are calculated using the beginning and ending years of each period for each respective region as calculated by the business cycle algorithm.

The primary technology classes in which a region has an RCA in a certain time period are in the portfolio of this region at this time. If the next time period the region gains an RCA in a technology this technology enters the portfolio of the region[7]. Using the portfolio of the region and the relatedness matrix of the previous time period one can calculate the relatedness density of this entering technology to the portfolio. The same can be done for technologies that were not present in the portfolio of a region but did not enter. The relatedness density is calculated by dividing the sum of the relatedness of the technology class under question to the technology classes in the portfolio by the sum of the relatedness of this technology class to all primary technology classes.

Empirics

The entry model, based upon the one used by Boschma et al. (2015), is used. In the regression a dummy variable acts as a dependent variable. Like in Boschma et al. (2015) an OLS is applied instead of a nonlinear specification like probit or logit. This is because the parameter estimates of nonlinear models might not be consistent when there are too many "0" in the dependent variable like is the case here (King & Zeng, 2001 *in* Boschma et al. , 2015) .

The regression is shown below. If a certain technology enters the technology space of a certain region in a certain time period the value of the dependent variable is 1. If it wasn't in the portfolio of a region and it didn't enter its value is 0. This is regressed on the relatedness density of the technology class to the portfolio of the region in the previous time period, an interaction variable between a dummy crisis and the same relatedness density, a dummy variable for crisis, city and technology related control variables and a city-fixed effect (φ), a technology-fixed effect (θ) and a time-fixed effect (τ).

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[6] Most authors (e.g. Van Eck & Waltman, 2009; Boschma et al., 2014; & Balland et al., 2015) use the index without the T factor. This formula is easier to compute and proportional to the one used here. The advantages of this formula are: that it is easier to read, a value of 1 means that there are exactly the same number of co-occurrences as could be expected in a random setting; & the resulting matrix can directly be compared over time.

[7] To prevent noise from regularly entering and exiting technologies the condition is added that a new technology must at least be present during to time periods.

$$Entry_{i,c,t} = \beta_1 Rel.Density_{i,c,t-1} + \beta_2 Interaction_{i,c,t-1} + \beta_3 Crisis_{i,c,t} + \beta_4 City_{i,c,t-1} + \beta_5 Technology_{i,c,t-1} + \varphi_c + \theta_i + \tau_t + \varepsilon_{i,c,t}$$

Due to the very preliminary stage in which this research is only the relatedness density variable, interaction variable, crisis variable and a single city specific control variable plus the fixed effects are included. The city specific control variable included is the estimated average population of the MSA at time t.

Other control variables are under development based on Boschma et al. (2015). Time-varying city specific characteristics that will be available soon are: the inventive capacity, calculated as the ratio of inventors to inhabitants; the MSA technological growth rate, calculated as the growth rate of the number of inventors in a MSA; and the technological specialization of MSA c, which is measured by the average location quotient weighted by the number of patents:

$$Specialization_c = \sum_i \frac{P_{ci}}{P_c} LQ_{ci}$$

Time-varying technological specific characteristics that are also being developed at this time are: Number of inventors per technology class, this is the total of inventors working on inventions related to a technology class; Technology class growth rate, measured by the growth rate of inventors working in a certain technology class; and the technological concentration, which is, like its city specific counterpart, measured by the average location quotient weighted by the number of patents but then by summing over cities:

$$Concentration_i = \sum_c \frac{P_{ci}}{P_c} LQ_{ci}$$

At this stage however only the fore-mentioned variables are available. Table 5 gives the summary statistics for the variables used.

Variable	Obs	Mean	Std. Dev.	Min	Max
Entry	999391	0.022431	0.14808	0	1
Relatedness density	999391	0.078699	0.126067	0	1
Crisis*relatedness density	999391	0.026411	0.082445	0	1
Crisis	999391	0.280364	0.449177	0	1
Average population	999072	404349.7	935617	4749.5	1.70E+07

Table 5. Summary statistics of the variables.

A first trial regression was executed using these variables. Three different models are tested: Model 1 is the base model. Testing if the large nation-wide crises have led to more related or unrelated diversification in regions that entered in crisis at that time. Model 2 & Model 3 are adaptations respectively excluding the war-related crises and only using the war-related crises.

First results

Table 6 below gives the results. As expected the coefficient on relatedness density is positive and significant. Confirming earlier presented results that relatedness to technologies in the portfolio of a region is an important predictor of entry. The variable of interest however is the interaction variable between the dummy crisis and this relatedness density. The coefficient on this variable is negative and significant at the 0.001 level. Meaning that the relatedness density is less an important factor during crises. This seems to confirm the theory of creative destruction that during large crises more unrelated innovations are made. The coefficient on crisis is negative and significant at the 0.05 level. This indicates that during crises technologies are less likely to enter.

	Model 1	**Model 2**	**Model 3**
	All Crises	w/o Wars	Wars Only
Relatedness density	0.0931***	0.0929***	0.0915***
	(38.63)	(38.41)	(37.43)
Crisis*relatedness density	-0.0272***	-0.0343***	0.00144
	(-7.05)	(-8.49)	(0.18)
Crisis	-0.00154**	-0.00258***	0.00855***
	(-3.04)	(-4.69)	(7.54)
Average population	-1.61e-09*	-1.83e-09**	-3.47e-09***
	(-2.37)	(-2.64)	(-4.40)
Technology F.E.	Yes	Yes	Yes
City F.E.	Yes	Yes	Yes
Time F.E.	Yes	Yes	Yes
Constant	-0.00698	0.0280	-0.0521
	(-0.97)	.	(-0.00)
Observations	999072	933369	784901
t statistics in parentheses, * p<0.05, ** p<0.01, *** p<0.001			

Table 6. Entry of Technologies during Crises.

The results tend to support the theory of Kleinknecht (1981) explained earlier. That innovation might be more radical during the crisis. As can be seen by the coefficient on the interaction variable. But that the actual swarming of innovations take place after in the period of growth after the crisis. This agrees with the coefficient on the crisis variable which shows that technologies are more likely to enter during periods of growth. It also agrees with fact that patenting activity increases during periods of growth. However these results are preliminary and more research on this is needed. Also Kleinknecht (1981) and most academics in long waves subdivide the two phases in cycles used here in 4 phases: expansion & boom during the growth and recession & depression during the crisis. The implications of this difference have to be investigated.

Interestingly when the war related crises are excluded the results do not change much see Model 2. But if the regression is ran using only the war-related crises the variable of interest suddenly is slightly positive and not significant. This seems to confirm that different types of crises lead to different types of diversification behaviour. In the long wave literature a lot has been written on the fact if wars should be included. The literature research of this paper is however not at a point to elaborate on this at the moment. In regional resilience literature diversification seems to play a role in every crisis. The results here show that regions do not diversify more radically during war-related crises. In the future this research hopes to explain this and take into account more different crises. Like local crises and shorter cycles.

NOTE: The three models have also been tested only using the periods of regional technological growth and regional technological crisis that overlap with large crises and the results seem robust.

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