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Konstantakis, Konstantinos N. and Michaelides, Panayotis G.

National Technical University of Athens, Systemic Risk Centre, London School of Economics

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Konstantinos N. Konstantakis

National Technical University of Athens

Panayotis G. Michaelides*

National Technical University of Athens

& Systemic Risk Centre, London School of Economics

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Abstract: The purpose of this paper is to deal with questions of instability and economic crisis, deriving theoretical arguments from Schumpeter's works and presenting relevant empirical evidence for the case of the US economy by sector of economic activity in the time period 1957-2006, just before the first signs of the global recession made their appearance. More precisely, we make an attempt to interpret the economic fluctuations in the US economy by sector of economic activity and find causal relationships between the crucial variables dictated by Schumpeterian theory. In this context, a number of relevant techniques have been used, such as cointegration analysis, periodograms, Granger causality tests as well as stepwise bi-directional causality test a la Dufour and Renault. Our findings seem to give credit to certain aspects of the Schumpeterian theory of business cycles. The results are discussed in a broader context, related to the US sectoral economy.

Keywords: Economic Crisis, US Sectoral Economy, Schumpeter, Business Cycles.

1. Introduction

The Western World is superior, in terms of economic growth, compared to the poverty in most parts of the world due to, among other things, its technological superiority. In the words of Mokyr (1990, preface): “The difference between rich nations and poor nations is not […] that the rich have more money than the poor, but that rich nations produce more goods and services. One reason they can do so is because their technology is better; that is, their ability to control and manipulate nature and people for productive ends is superior”.

In the meantime, it is also true that the history of technological change and innovation contains several uneven periods in the history of particular economies. For instance, several nations are quite rich in technological progress and innovation. However, several peaks are often followed by periods during which the rate of technological change falls. So far, no satisfactory explanation has been found. As Thomson (1984, p. 243) has argued: “[t]echnical change is like God. It is much discussed, worshipped by some, rejected by others, but little understood”. According to Mokyr (1990, p. 6), the reason is simple: “The diversity of technological history is such that almost any point can be contradicted with a counterexample.” However, “Technological change is never automatic. […] there usually must be a combination of considerations to…make it possible: (1) an opportunity for improvement…, or a need for improvement…and (2) a degree of superiority such that the new methods pay sufficiently to cover the costs of the change” (Landes 1969, p. 42).

In this paper, we are dealing with questions of instability and economic crises, deriving arguments from Schumpeterian theory and presenting relevant empirical evidence for the case of the USA by sector of economic activity in the time period 1957-2006, based on relevant quantitative techniques. In the Schumpeterian tradition, a crisis is the by-product of innovative activity which can create long waves that are caused by the clustering of innovations. Schumpeter conceptualized business cycles as disturbances in the equilibrium and a return to a new equilibrium point which gives the process a cyclical character. The paper investigates how technological change affects economic activity in the US sectoral economy for the period 1957-2006.

This work contributes to the literature in the following ways: First, it provides an extensive review of the literature on the subject and introduces the relevant quantitative framework which combines, spectral analysis, cointegration, Granger causality and stepwise causality tests a la Duffour and Renault. Second, based on these quantitative approaches, the paper offers a complete investigation of a famous postulate of the core of the Schumpeterian theory for the US economy, and it is the first, to the best of our knowledge, to do so by sector of economic activity. Third, the paper uses a wide dataset to examine the U.S. economy for the period 1957-2006, just before the first signs of the US and global economic recession made their appearance, in order to avoid getting skewed and biased results.

The structure of the paper is as follows: section 2 presents a selective review of the literature on technology; section 3 presents the theoretical framework drawing on Schumpeter's original works; section 4 sets out the methodological framework; section 5 offers a brief discussion of the empirical findings; finally, section 6 concludes.

2. Technology in *Economics*

Technological change expresses various kinds of knowledge that can make it possible to produce (i) a qualitatively superior output (or even a completely new output) or (ii) a greater volume of output (Rosenberg 1982, p.3). The majority of studies and essays on technological change regard it only as a cost reducing-phenomenon, which introduces new processes that reduce the total cost while the product remains unchangeable. However, following the same author (Rosenberg 1982, p. 4), "to ignore product innovation and qualitative improvements in products is to ignore what may very well have been the most important long-term contribution of technical progress to human welfare".

Kuznets (1930) focused on the great importance of innovation to economic growth and provided econometric evidence on the existence of a business cycle with a length of approximately twenty (20) years for the US economy. According to his findings the existence of such a cycle could be attributed to investments in infrastructure. Also, for Schumpeter, the clustering of innovations is the driving force for business cycles creation and emphasized the importance of new products and the high degree of instability caused to capitalist economies by technological innovation (Schumpeter 1939, 1942). [1] Following Nunes (2016), for Schumpeter entrepreneurship is the expression of the human impulse to be creative and the role of the entrepreneur in a developing/growing economy is to destroy the *status quo* in order to create a new cycle and a new flow, in an inter-temporal context. For Schumpeter, economic growth is generated by new business ideas and persistent innovations (Landström, 2005). In fact, Schumpeter argued that entrepreneurial rewards are obtained from the temporary monopoly scenario that arises as the entrepreneur successfully develops his business through "new combinations" of ideas and resources (Schumpeter, 1934). Additionally, for Schumpeter, innovating, improving existing goods and services, creating or expanding markets, and improving production processes and organizational structures were some of the leading characteristics of the entrepreneur. Schumpeter's emphasis on innovation and its impact on capitalist economies was extended by Strassmann (1959) whose main objections to Schumpeter's theories was that 'they do not adequately explore the process of technological change as a series of complementary, mutually reinforcing developments' (Strassmann 1959 p. 218).

Another school of thought that emphasizes the role of technological progress is traced back to Marx who mostly emphasized on the importance of social forces leading to technological progress (Marx 1867). Usher (1954) has probably offered the "most carefully articulated expression, in the twentieth century, of the view of technological progress that emphasizes continuity" (e.g. Rosenberg 1982, p. 6). Usher (1954) was mainly concerned with the origins and the nature of the inventive process and not its consequences. In specific, Usher (1954) identified three general approaches to the problem of explaining the emergence of invention, namely the trascentalist, the mechanistic process and the cumulative synthesis. Ruttan (1959) argued that Usher (1954) established the theoretical framework for a theory of innovation that Schumpeter was lacking. Furthermore, according to Ruttan (1959), Usher's (1954) cumulative synthesis theory provided a unified theory of social process by which 'new things' come into existence, and it was broad enough to encompass the notions of invention, innovation and science. Also, Gilfillan (1935a,b) argued that technological change consists of numerous minor modifications, introducing the notion of 'Sociology of invention' in the literature of technology and innovation.

[1] As Freeman wrote: "Most economists when they do consider technical change and the long-term dynamics of the system, turn to Schumpeter, and it is true that almost alone among major twentieth-century economists Joseph Schumpeter *did* attempt to place technical change at the heart of his system and did also address problems of social and institutional change" (Dosi et al., 1988, p.5).

Fishlow (1966) had a similar view of technological change, and provided a thorough investigation of US railroad sector incorporating Schumpeter's and Gilfillan's ideas on the role of innovations in order to explain the fluctuations of the sector. In a similar vein to Gilfillan and Fishlow, Hollander (1965) and Enos (1962)provided evidence in favor of the fact that re-invention tends to contribute just as much to technological progress as the original technological breakthrough does.

Of course, the efforts of economists and economic historians to develop and present reliable quantitative or even qualitative explanations of the contribution of technology to economic growth were serious but have not always ended up in success. After World War II, the recognition of the crucial role of technological change in economic growth has its roots in the work of Abramovitz (1956) and Solow (1957), who were probably the first to quantify the contribution of technological progress in the growth of the US economy. The authors found that only a portion of the growth in the American output was the result of an increase in capital and labour, while a large part of it remained unexplained, the so-called, "residual". In that context, Solow (1956, 1957) suggested using an exogenous factor, called "technological change". The econometric studies by Denison (1962a, 1962b, 1967), and Denison and Chung (1976), estimated that the components of the residual were the advances in knowledge and the role of economies of scale. However, these studies did not manage to come to realistic conclusions, and after some other studies had been conducted by Griliches (1957), Parker and Klein (1966), Parker (1967) leading to similar results, the assumption of the exogenous nature of technological change was serious questioned. In a seminal paper, Jorgenson et al. (1967) argued that the unrealistic results of previous studies in the Solow residual are due to inaccuracy measurement errors. In specific, he argued that TFP should be computed as the difference between the rate of growth of real product and the rate of growth of real factor input. More recent attempts to explain thesize of TFP were made by, among others, Hart (1995) who argued that TFP is best explained by the dual increase in the average output-price/input-price differential resulting from the squeeze in the rate of profits. In analternative approach, Cantner and Kruger (2007) suggested that the Solow residual should be determined using a frontier analysis in an attempt to get more accurate estimates.

A new series of articles by Johansen (1959), Solow (1960) and Nelson (1964), treated technological change as endogenous, embodied in new technological goods. Improvements to these articles came through the works of Kaldor and Mirlees (1962), and Arrow (1962) and were extended by Uzawa (1965), Phelps (1966), Shell (1967), and Gomulka (1970, 1971). As far the literature relating technological progress and innovation at the firm level is concerned, the seminal studies trying to test empirically this relation, were those of Horowitz (1963), Hamberg (1964), Mansfield (1964), Scherer (1965a,b), Comanor (1967), Philips (1971), Malecki (1980), Link (1980), Meisel and Lin (1983), Scherer (1984) and others.

Some new efforts by Romer (1986), Lucas (1988) and Scott (1989) who treat technology as "internal" to the firm, have taken place. Accordingly, the articles by Romer (1990), Grossman and Helpman (1991), argue that firms buy their innovations from the technological sector. In a breakthrough paper, Aghion and Howitt (1992) argued that the innovative activity should be categorized by the magnitude of the impact of each type of innovation on economic growth. On the other hand, a series of studies outside the neoclassical view made an effort to explain the differences in economic growth among nations. These approaches are in the spirit of Gerschenkron (1962), Ohkawa and Rosovsky (1973), and suggest that new institutions should be developed in order to enable nations to increase their growth potential and reduce the great inequality observed among nations (Abramovitz 1986, 1994, Nelson 1993 and Lundvall 1992). Relatively recently, Aghion et al. (2005) managed to derive an inverted U-shape relationship between innovation and competition in a general equilibrium framework which shed new light on the innovation dynamics that drive productivity forward. Finally, under the prism of Schumpeterian theory, Smythe (2009) provided a thorough analysis of the Great Merger Movement that took place in American manufacturing in the period 1895-1904. According to this work, this movement can be attributed to competitive pressures that were associated to a significant number of technological innovations that occurred at the end of the 19th century, whose incorporation in the production process would yield uncertain benefits, in a competitive environment and, thus, competition had to be restrained. In fact according to Cajaiba-Santana (2014), research on social innovation has been polarized between agentic and structuralist approaches.

In a similar vein, in this work, we deal with questions of causality in business cycle theory deriving theoretical arguments from Schumpeter's work.

3. Theoretical Framework

As we know, Schumpeter's work may be considered as the starting point for economics of technical change, while Schumpeter on the whole could be considered as pioneer of evolutionary economics(Alcouffe and Kuhn 2004, 226).[2]

In the first Japanese edition of his *Theory of Economic Development* Schumpeter noted that his purpose had been to create "a theoretic model of the process of economic change in time [. . .] to answer the question how the economic system generates the force which incessantly transforms it" (Clemence, 1951, 158–159). Schumpeter started this book with a treatise of circular flow which –excluding any innovative activities – leads to a stationary state. The stationary state is described by Walrasian equilibrium taking account of the interdependences of economic variables but applicable only to a stationary process, i.e. one which adapted itself to forces acting on it.Schumpeter described this equilibrium as "stationary flow" (Schumpeter 1912, ch. 1) characterized by the absence of any change. He made clear that this "stationary flow" is only a theoretical abstraction and serves as a reference point (Schumpeter 1928).

According to Schumpeter: "Development is the distinct phenomenon entirely foreign to what may be observed in the circular flow or in the tendency towards equilibrium". "It is spontaneous and discontinuous change in the channels of the flow, disturbance of equilibrium which forever alters and displaces the equilibrium previously existing" (Schumpeter 1983 [1934], 64). Development may be related etymologically to some kind of progress; a positive procedure; and in that sense it may be related to some kind of teleology.[3]The great Austrian theoretician defined economic development as "such changes in economic life as are not forced upon it from without but arise by its own initiative, from within" (Schumpeter 1912, 63). It was a phenomenon foreign to what might be observed in the tendency towards equilibrium (*ibid*, 64). It involved discontinuous change in the channels of flow, disturbance of equilibrium, which forever

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[2] Schumpeter's relation to the term evolution is very often misleading, departing from his cautious attitude against the biological analogy and from his argument against the dilettante use of the term "evolutionary" in economics, especially in chapter II (*"The fundamental phenomenon of economic development"*) of the 1934 English version of his *Theory of Economic Development* (p. 57.) However, in a letter to Stewart Morgan (18 May 1934), Schumpeter referred to his book as *The Theory of Economic Evolution*(see Siebeck, p. 267), and in his subsequent *Business Cycles* the term "evolution" is a key ingredient.

[3]For Schumpeter, teleology is "the attempt to explain institutions and forms of behavior *causally* by the social need or purpose they are supposed to serve; which is not always erroneous" (Schumpeter 1954, 58).

altered the equilibrium state previously existing. He wrote that: "[W]hat we are about to consider is that kind of change arising from […] the system which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps. Add successively as many coaches as you please, you will never get a railway thereby" (Schumpeter 1912, 64). Economic development depends primarily upon productivity increases based on technology and innovation. More precisely, for Schumpeter this concept covered the following cases: "1. The introduction of a new good […] or a new quality of a good. 2. The introduction of a new method of production […]. 3. The opening of a new market […]. 4. The conquest of a new source of supply […]. 5. The carrying out of the new organisation of any industry" (Schumpeter 1912, 66).

In this spirit, Schumpeter used the term 'technological progress' to characterize these changes (Scherer 1992: 1417), which account for the greater part of economic development. He distinguished this process from growth due to the gradual increase in population and capital. He wrote: 'The slow and continuous increase in time of the national supply of productive means and of savings is obviously an important factor in explaining the course of economic history through centuries, but it is completely overshadowed by the fact that development consists primarily in employing existing resources in a different way, in doing new things with them, irrespective of whetherthose resources increase or not" (Schumpeter 1942, 65).

In the Schumpeterian system, technology is the cornerstone of economic evolution and appears as the making of new combinations. Fluctuations are related to three different sources, namely: external factors (i.e. changes in commercial policy, diseases, changes in gold production because of new discoveries, revolutions and disasters), growth (i.e. changes in economic data which occur continuously in the sense that the increment / decrement per unit of time can be currently absorbed by the system without perceptible disturbance) and innovation (i.e. the historic and irreversible change in the way of doing things and more specifically changes in production functions which cannot be decomposed into infinitesimal steps).

According to Los and Verspagen (2007) technology and innovation efforts can be classified in two large categories: "process- oriented" and "product oriented". "Process-oriented" technological and innovative efforts aim at lowering the unit cost of producing a given type of output maintaining a constant quality. On the other hand, the main purpose of "product oriented" technological and innovative efforts is to produce either completely new products or qualitative different varieties of existing products. Of course, innovation is a qualitatively different phenomenon from invention: “innovation is possible without anything we should indentify as invention, and invention does not necessarily induce innovation, but provides of itself [...] no economically relevant effect at all” (Schumpeter 1939, 84). Also, Schumpeter asserted that the social process which produces innovations is distinctly different “economically and sociologically” from the social process which produces inventions (e.g. Ruttan 1959, 597). Schumpeter distinguished innovation from invention by arguing that “innovation is endogenous to the system, but is finally determined by the entrepreneurial function, that unique capacity to make combinations” (Freeman and Louçã 2001, 59).

In the same spirit, the difference between innovation and invention has been extensively discussed in Van Duijn (1983) who argued that diffusion, i.e. the large-scale distribution of innovations, is the dominant force behind long waves. For Van Duijn (1983), invention was the creation of an idea while innovation was the implementation of this idea. Van Duijn’s(1983) theorywas based on three basic principles, namely: (a) innovation; (b) innovation life cycles and (c) investments in infrastructure. He suggested that innovations and innovation life cycles were the boosters of the growth process, which were additionally strengthened by investments in infrastructure. He distinguished the following four distinct types of innovations: (a) important product innovations, which were able to create new industries; (b) important product innovations, in already established industries; (c) process innovations in existing industries and (d) process innovations in basic sectors (such as oil refineries and the steel industry). Of course, as Kurz and Salvadori (1995) have argued, whether an invention will be transformed into an innovation lies on the distribution of income. In fact, Kurz (2007) presented a model that could incorporate two distinct industries so as to investigate the role of invention and innovation and their interrelationship in a (neo-)Schumpeterian framework.

Schumpeter also famously argued that economic systems do not achieve equilibrium. They just move into “neighborhoods of equilibrium [...] in which the system approaches a state which would, if reached, fulfill equilibrium conditions” (Schumpeter 1936, 45). In fact, in his *Business Cycles* Schumpeter (1939, 106) emphasized that major innovations are introduced around the neighborhood of equilibrium given that conditions are ideal. For him economic development is the result of innovation, i.e. “the outstanding fact in the economic history of capitalist society” (Schumpeter 1939, 61) and innovation is the leading force in what he calls “evolution”.

Economic evolution is however discontinuous because “innovations are not evenly distributed over time, but appear if at all discontinuously in groups, swarms or clusters” (Schumpeter 1939, p. 223). These discontinuities make innovations a force in the economic system and innovations which do not produce them cannot be a force in the economic evolution of a social formation: “[The] historic and irreversible changes in the way of doing things we call “innovation” [...] *The kind of wave-like movement, which we call the business cycle, is incident to industrial change and would be impossible in an economic world displaying nothing except unchanging repetition of the productive and consumptive process*” (Schumpeter 1935, 4; emphasis added).

The crystallization of technical change in the Schumpeterian system is the business cycle. In fact, for Schumpeter the business cycle is defined as the wave-like movement which is incident to industrial change. The way in which Schumpeter conceived of the cyclical features of the economic process is summarized by Elliot (1993, p. 14): “development occurs through a cyclical process” and as a result “cyclical fluctuations are no barrier to economic growth and recessions are not necessarily indicators of capitalism failure or breakdown”.

The typical interpretation of Schumpeter’s analysis is that long waves are causedby the clustering of innovations.Schumpeter conceptualized long waves as disturbances in the equilibrium and a return to a new equilibrium point which gives the process its cyclical character. All economic systems have an esoteric tendency towards equilibrium moving toward these “neighborhoods” after the disruptions have exhausted themselves. The most important characteristic of these “neighbourhoods” is that conditions are stable (Schumpeter 1912, 214).

Of course, in the Schumpeterian doctrine the main force behind the cyclical behavior of economic activity is innovative activity. According toHanusch and Pyka (2007), Schumpeter conceptualized Kontradieff’s long waves which consist of long lasting cycles of a length of approximately 60 years, to be triggered bya constellation of interdependent and mutually supportive technical and organizational innovations (Louca 2007). Such a long run cycle is overlapped by the so-called 'Juglar cycle' that has an approximate length of 10 years and is caused by the clustering of innovations mainly in infrastructure. For Schumpeter, Juglar cycles again are overlapped by the so-called ‘Kitchen cycles’ with a length of approximately 40 months, which are caused by investment in inventory.

Therefore, in Schumpeterian business cycles theory there are three[4] (3) overlapping cycles that dictate the ongoing, eternal process of the economy to jump discontinuously from one equilibrium point to another[5], while the locomotive behind both the cycles creation and equilibrium jumps lies on the clustering of technological and innovative activity that is inherently an endogenous characteristic. Innovations tend to cluster because when something fundamentally new and untried has been succeeded it is much easier not only to do the same thing again but also to do similar things in different ways.

4. Methodology

The main purpose of this section is to testthe Schumpeterian business cycles theory using modern econometric techniques. In fact our work complements the work of Noori et al. (2016), and, partly, the work of Oner and Kunday (2016) who used log–log regressions and found that R&D expenditure has a close relationship with unit size. Analytically, in this work, we provide a framework under which the investigation of business cycles is examined in the context developed by Joseph Schumpeter.

Stationarity test

According to the Schumpeterian tradition, business cycles are perceived as deviations from an equilibrium point towards a new one. In order to indentify this deviation we first need to know whether the data at hand are stationary or not. First, we examine the stationarity characteristics of each time series. Due to the fact that trend stationarity is a much stronger characteristic of the system than proposed by Schumpeter, who did not specify the transition from one circular flow position to another, it is an expected result of Schumpeterian doctrine that our time seriesare non-stationary as Foster (2007) suggested, in order to be consistent with the Schumpeterian view of business cycles.

Spectral Analysis

[4] Nevertheless, several authors (e.g. Ambramovitz 1968, Fenoaltea 1988) suggest that there is a fourth cycle, the Kuznet's cycle with a length of approximately 30 years that could be included in Schumpeter's theory.
[5] For an extensive review of cycle dynamics in a Schumpeterian spirit see, among others, Silverberg (2007).

Next, Schumpeter conceptualized business cycles as disturbances in the equilibrium and a return to a new equilibrium point which gives the process a periodic character. Thus, form an econometric perspective we are about to examine the periodical pattern in the data. If periodicity is not present in our analysis then any Schumpeterian argument could not possibly have any valid ground.

In this context, we investigate the periodicities of business cycles assuming that the actual fluctuations of the data are chiefly of a periodic character. The length of the period in an economic series may, in general, be variable. Therefore, we understand by the term “period” the average length of the cycles and the periodogram can assist in finding these average lengths. Our work is consistent with Metz (2010) and Baubeau (2008) who argue that, in the presence of regular cycles in the time series, spectral analysis is appropriate for testing for cycles.
In this context, peaks in the periodogram represent the cyclical behavior (frequencies) in the data. See Diagrams VII-VIII.

Cointegration

Furthermore, we have to check for cointegration between the variables that enter the model, since if cointegrating relationships are present then there exists a long run equilibrium relationship between the variables under investigation. It is exactly upon the existence of this equilibrium relationship that Schumpeterian business cycles were founded, since progressive evolution of innovative activity expressed through technology, leads to the evolution of economic activity as a whole.

Causality Test

Next, we conduct bivariate causality tests between technology, as expressed through R&D, and real output GDP. The notion of causality especially between R&D and real output is very crucial in Schumpeterian business cycle theory, since according to Schumpeter the main force behind the eternal movement of economic activity from one equilibrium point to another is technology, which is expressed as the clustering of innovative activity. Meanwhile, the use of causality tests is very extensive because they relate variables and find predictive powers among them. Causality tests have been extensively used to count the effects of technology. There is a plethora of studies trying to link R&D expenditures with variables such as national output, trade, productivity, profitability, etc (Salim and Bloch, 2007; Verbeek and Debackere, 2006; Thirtle et *al.,* 2002; Heshmati and Loof, 2005).

Stepwise Causality

Unfortunately, simple pairwise bi-variate Granger causality tests could have important implications for our analysis. For instance, for our purposes, a fundamental variable in the model such as R&D expenses may appear to be of no predictive ability for GDP_t one period ahead GDP_{t+1} on its own. However, if $\text{R\&D}_t$ could help predict some other third fundamental variable Z_{t+1} such as a Total Investment which, in turn, could help predict the GDP_{t+1} one period ahead, then $\text{R\&D}_t$ could help predict GDP_{t+2} two periods ahead. This has been the core of the concept of step by step causality, originally developed by Dufour and Renault (1998) and Dufour et *al.* (2006). Since the notion of causality lies in the core of Schumpeter's business cycles we make use of the concept of short-run and long-run causality measures in order to account for the timing of causality in our investigation.

5. Empirical Results and Discussion

5.1 Data and Variables

As we have seen, a major problem in examining technological change is that it takes many different forms. In that sense, there is no generally accepted measure of technological change and all measures are imperfect. As a result, we use the most popular measure in order to quantify technological change, i.e. R&D expenditures given that it is widely argued that cumulative R&D is an important determinant of technology.[6]

[6]Of course, another variable that could serve as an alternative indicator for technological change is patents. However, as several authors have convincingly argued (e.g. Smith 2006), patent data would provide only a very crude proxy, at best, for what is meant by technological change and innovation. After all, sectoral data on patents were not readily available to us, based on the classification at hand. Of course, further investigation based on patents could be helpful.

We make use of data for the U.S economy for the period 1957-2006 just before the first signs of the US and global economic recession made their appearance referring to the fourteen (14) main industrial sectors of the economy. For the Industry Classification see Table IX. Our investigation stops in 2006 since, at post-2006 era, the dynamics of the traditional economic structures changed dramatically, both in the USA and globally, a fact consistent with the work of Urbano and Aparicio (2016), who found significant evidence of disruption in global economic growth in particular and global dynamics in general in the pre- and post- crisis periods, respectively. Hence, any examination beyond this period would produce skewed and biased results. In terms of the variables employed: (R) is the total R&D expenses[7], (Y) is the gross domestic product. All observations are in billions of dollars in 1957 prices. The data on R&D come from the National Scientific Foundation of U.S and on Y come from the National Bureau of Economic Activity.

5.2 Result Analysis

To begin with, the stationarity properties of the various macroeconomic times series were checked.As expected, most macroeconomic variables in levels are non-stationary with the exception of aggregate output for sectors 1 and 2, respectively. See Tables I-II. According to the classification presented in table XII, sector 1 accounts for agriculture[8], forestry and fishing, while sector 2 accounts for mining[9] petroleum and coal. Stationarity of these sectors suggests that the data regarding aggregate output, exhibit smooth econometric properties with rather constant mean value, variance and covariance throughout the period of our investigation. This could be attributed to the fact that, over the time period 1957-2006, the productive capabilities in both sectors remained almost unchanged since their available resources have remained practically unchanged.

The periodograms reveal the periodicities of the time series and are shown in Diagrams III-IV. The Aggregate Output in most sectors seems to follow the same pattern since a short term cycle (3-6 years) is evident. The existence of such a cycle gives credit to the Schumpeterian

[7] According to Grupp (2007), R&D expenses is among the most important variables in the cluster of resource indicators that accounts for the measurable function technology in a (neo)-Schumpeterian sense.

[8] For an extended discussion on the role of US Agricultural sector, see Chang and McCarl (1993).

[9] For more extended facts regarding the petroleum and mining sector in US economy, see the National Mining Association of US.

doctrine since it accounts for a Kitchin cycle which is an inventory cycle. In contrast, R&D exhibits in all sectors a short-term cycle (1-3 years) and in some sectors a mid-term cycle (12-15 years) and a long term cycle (30-35 years), see de Groot and Franses (2012). The existence of such cycles that account for Juglar and Kuznets cycles, are the effect of fixed and infrastructure investment activity, respectively (Low, 1984). The fact that a Kondrantieff cycle is not directly observable in our empirical results is naturally attributed to the limited time span of our investigation (50 years), which is not long enough to capture a cycle that has a period of 60 years. In fact our finding is consistent with the prominent work of Korotayev et al. (2011) who also found that in the US patent dynamics the K-wave pattern is significantly less pronounced than in the world dynamics. In fact, based on their findings the K-wave pattern of the US economy is rather vague since it is not as clear and regular as in the world invention dynamics. However, it is widely argued (e.g. Krafft, 2007, Perez 2007, Korotayev 2011 and Wilenius and Casti 2015) that that the development of the US economy in the early 90's is the effect of a 5th Kondratieff cycle which was triggered among others by the extensive use of microprocessors in all sectors of economic activity. In general our empirical findings are consistent with the findings of de Groot and Frances (2008) who argue that economic variables always display multiple cycles, with cycle periods that apparently do not interfere. The sum of all these cycles mimics erratic behavior, but underlying constellations of cycles are of such a nature that stability of economic variables is preserved. Hence, due to these sets of cycles, economies can handle exogenous shocks that might otherwise put them off balance.

Next, the results of the Johansen co-integration test for all sectors of economic activity (see Table V) show that the variables are co-integrated. Thus, the existence of a long run equilibrium relationship between R&D expenses and Aggregate Output in all sectors is evident. This, in turn, is fully consistent with the Schumpeterian view of business cycles where technology forces output to move from one equilibrium point to another, since in lack of cointegration any long run relationship between the variables would have no valid grounds.

The coefficients α and β of the cointegrating relation among the variables of Aggregate Output and R&D expenses for all fourteen (14) sectors are presented in tables VI-VII. The Coefficient α denotes the speed of adjustment (convergence) towards equilibrium. Values of α close to zero imply slow convergence. A larger value of α suggests a faster convergence in cases of short-run deviations from equilibrium. Coefficient β denotes the long run relationships among the variables In brief, the speed of adjustment that aggregate output has towards equilibrium is rather slow for the majority of sectors, while the speed of convergence for R&D expenses in most sectors is higher than that of aggregate output, implying that R&D cycles have a pro-cyclical character compared to aggregate output cycles (see Ouyang 2011).In addition, the equilibrium levels of aggregate output are rather smaller than those of R&D expenses in all sectors implying that R&D's long run equilibrium exhibits more stable properties than those of aggregate output.

In addition, due to the existence of cointegration among the variables for every model under investigation, the Granger causality test was conducted using the appropriate Error Correction Model (ECM), where the optimal lag length was selected according to Hsiao's (1981) methodology, as extended by Ahking and Miller (1985) according to which the lag length should be chosen based on with Akaike's Final Prediction Error (FPE) criterion.

The results of the Granger causality tests (see tables VIII-IX) reveal straightforward bidirectional causality in most sectors between R&D and Real Output with only a few exceptions. The fact that in most sectors R&D expenses dictate the evolution of aggregate output gives credit to the Schumpeterian view of business cycles, since clustering of innovations force economic activity to shift from one equilibrium point to another, a finding consistent with the work of Rasiah et al. (2016) and Noori et al. (2016) who also validated this Schumpeterian view using data on Taiwanese semiconductor industry and Iranian firms, respectively. Regarding the fact that in many sectors Granger causality tests show that output causes the evolution of R&D expenses, this can be attributed to the fact that in the majority of sectors, R&D expenses are a constant proportion of the total output of each sector.

As far as the sectors that according to Granger tests show that R&D expenses do not cause the evolution of aggregate outputare concerned, only two of them seem to follow that pattern.Precisely, only in sectors 5 and 13 R&D fails todictate the evolution of aggregate output. According to the classification employed (TableXII), sector five accounts for food, beverages, wood, furniture and metal products, while sector thirteen accounts for educational organizations.For sector five, the inability of R&D to Granger cause the evolution of aggregate output can be attributed to the very low productivity growth that the specific sector exhibits (see Huang 2003,Gopinath and Carver 1998).The same inability that sector thirteenexhibits, can be attributed to the fact thatthe main role of most educational organizations lies on knowledge and technology creation and to their diffusion in other industries (Jaffe 1989; Carayannis et al. 2000 and Abramovsky et al. 2007).

The results of the Duffour and Renault stepwise causality test (see Diagram X-XI)are largely consistent with those obtained through Granger tests, since bidirectional causality between the variables of R&D and aggregate output is evident in all sectors. In specific, in most sectors, R&D expenses dictate the evolution of aggregate output with a lag length between one and six years, consistent with the periodicity that most sectors exhibit regarding R&D. This, in turn, gives credit to the Schumpeterian theory of business cycles, since clustering of innovative activity is evident in most sectors, which in turn promotes the aggregate output evolution of each sector. Nevertheless, sector 13 which accounts for educational organizations seems to cause aggregate output with a significant lag, in contrast to the rest of the sectors. This, in turn, could be attributed to the fact that the aggregate output of this specific sector is knowledge and technology and its diffusion to the rest of the sectors, is rather time consuming (e.g. Jaffe et al., 1993; Anselin et al., 1997; Aghion and Howitt 1997; Anselin et al., 2000; Stoneman 2002; Acosta and Coronado, 2003; Agrawal and Cockburn, 2003; Audretsch et al., 2005; and Acosta et al., 2011b). Moreover, the results suggest that, in all sectors, output immediately dictates the evolution of R&D i.e. causality peak for one (1) lag, in line with the fact that R&D expenses in all sectors are a proportion of output.

6. Conclusions

In this paper, we built on Schumpeterian insights to examine economic instability for the case of the US sectoral economy for the period 1957-2006. Schumpeter conceptualized business cycle as disturbances in the equilibrium and a return to a new equilibrium point which gives the process its cyclical character. We assessed the co-movements between the raw variables of each time series observed through co-integration tests and found that technological change is strongly related to output. Also, we conducted bivariate Granger causality and stepwise Dufour and Renault causality tests between real output and technological change in order to assess the timing pattern of causality.

Our empirical findings give credit to certain aspects of the Schumpeterian theory of business cycles. An interesting finding is that most economic time series exhibit, roughly speaking, a similar pattern characterized by periodicities exhibiting a short-term cycle (Kitchin cycle); a mid-term cycle (Juglar cycle) and a long term cycle (Kuznets cycle). Finally, the results have been discussed in a broader context, related to the US sectoral economy.

This work contributes to the literature in the following ways: first, it introduces a relevant methodological framework; second, based on these econometric techniques, the paper offers a complete investigation of Schumpeterian business cycle theory for the US economy, and it is the first, to do so by sector of economic activity. Third, the paper uses a wide dataset to examine the U.S economy for the period 1957-2006, just before the first signs of the US and global economic recession made their appearance, in order to avoid getting skewed and biased results.

Given the fact that technology is crucial for economic growth, our estimates are important. We hope that that our research could help inspire further research on economic fluctuations. Last, but certainly not least, we hope that this works could help in promoting dialogue between researchers of technology and economic analysis, working in various strands and schools of economic thought. No doubt, future research on the subject would be necessary.

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APPENDIX A: Result Appendix

Table I – R & D (r) Augmented Dickey Fuller Test

Table II – Aggregate Output (Y) Augmented Dickey Fuller Test

Diagram III-Periodograms of Aggregate Output (Y)

Diagram IV- Periodograms of R&D (R)

Diagram V-Duffour Renault stepwise causality R&D (R) causes Aggregate Output (Y)

Diagram VI-Duffour Renault stepwise causality Aggregate Output (Y) causes R&D (R)

Table VII-- Granger causality

Table VIII- Ganger causality

Table IX- Sectors of U.S economy by NACE classification

Tables I & II- Augmented Dickey Fuller Test

Table I- R&D expenses (R)

sectors	p-value	stationarity
1	0.89	No
2	0.87	No
3	0.82	No
4	0.88	No
5	0.77	No
6	0.7	No
7	0.81	No
8	0.85	No
9	0.85	No
10	0.73	No
11	0.83	No
12	0.86	No
13	0.83	No
14	0.82	No

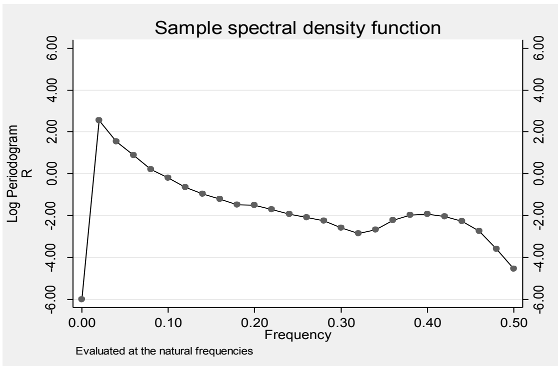
Table II-Aggregate Output (Y)

sectors	p-value	stationarity
1	0.00	Yes
2	0.00	Yes
3	0.77	No
4	0.89	No
5	0.79	No
6	0.84	No
7	0.81	No
8	0.91	No
9	0.79	No
10	0.84	No
11	0.82	No
12	0.89	No
13	0.70	No
14	0.73	No

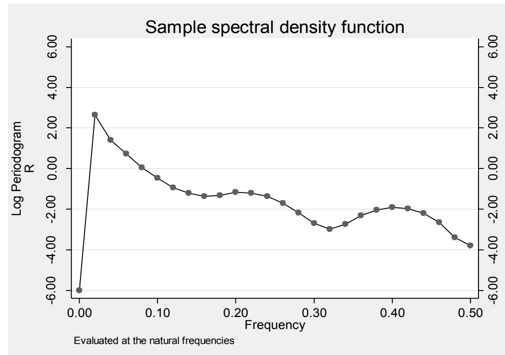
Diagram III-

Periodograms of R&D expenses (R) in natural frequencies

Sector 1



Sector 2



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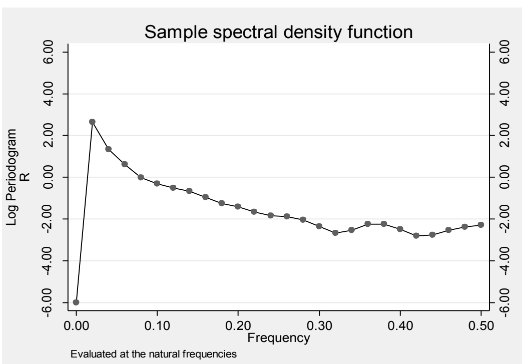

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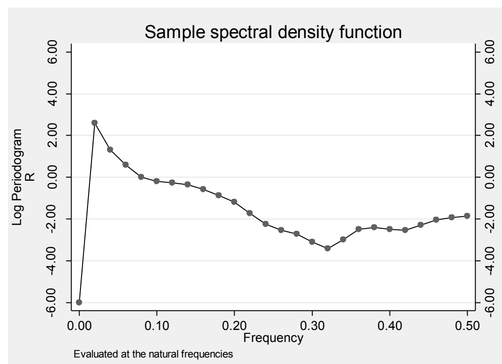

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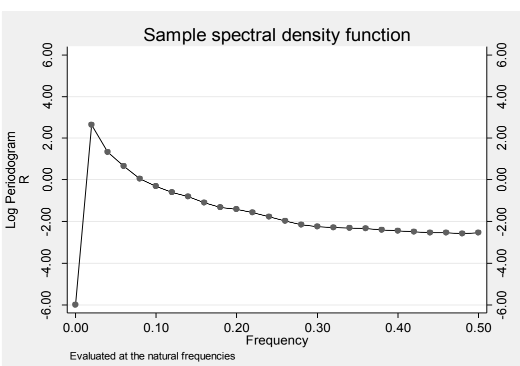

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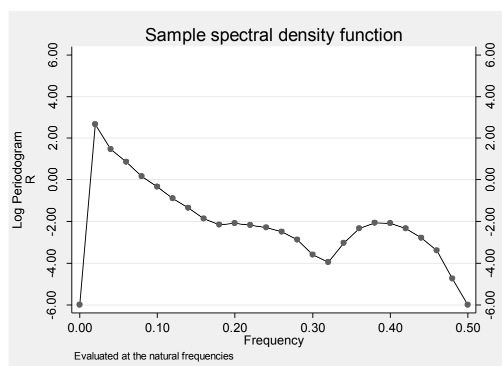

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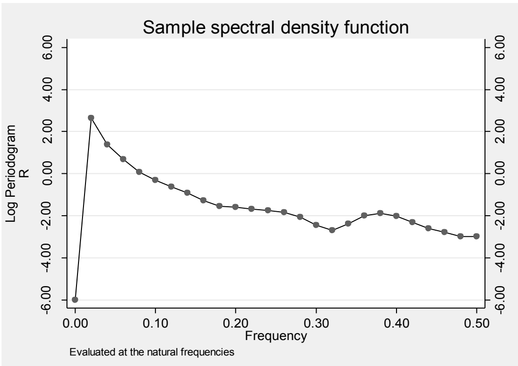

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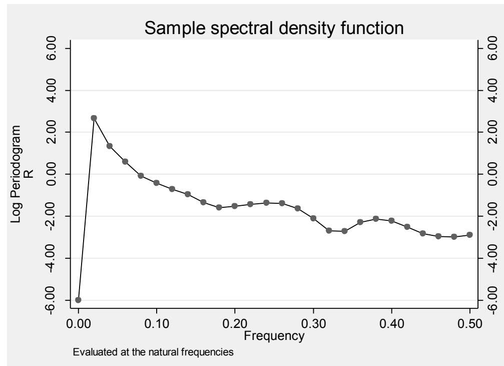

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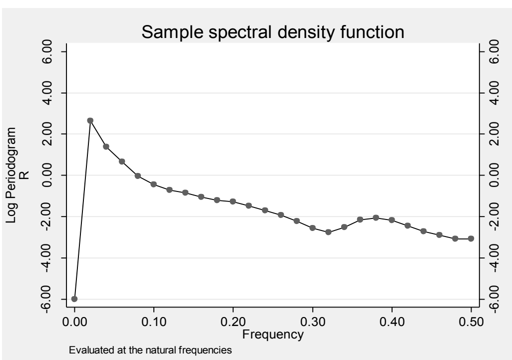

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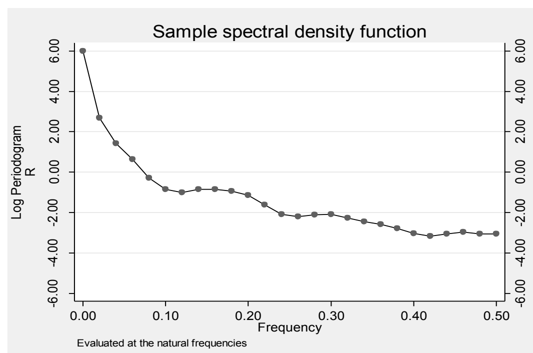

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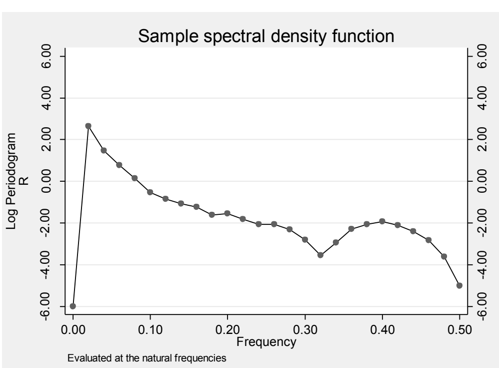
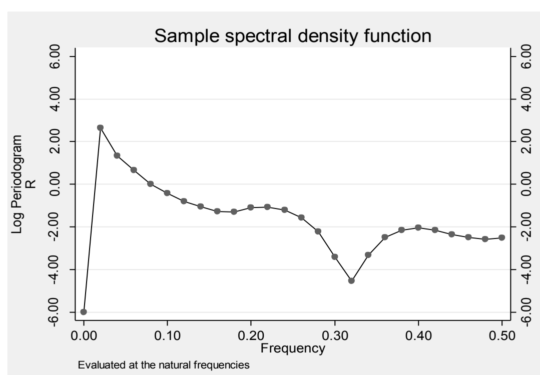
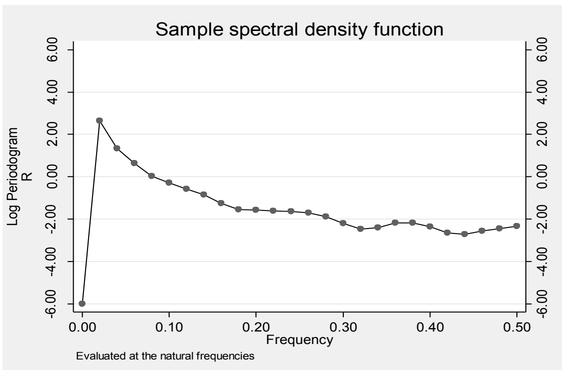


Sector 12



Sector 13



Sector 14

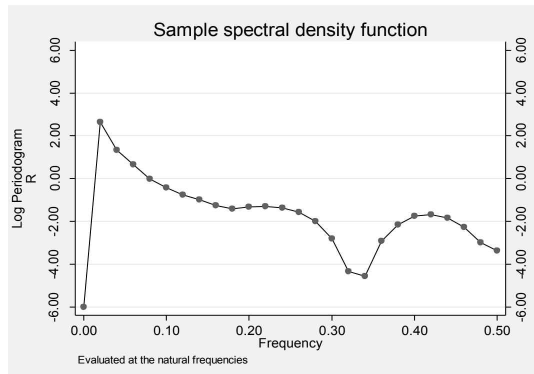
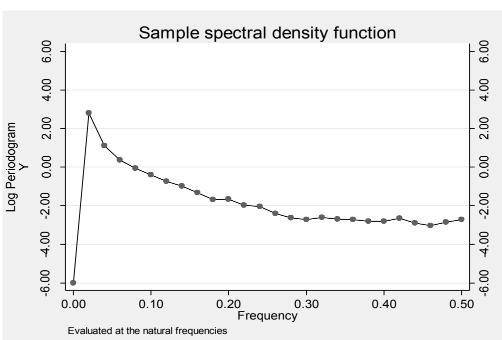


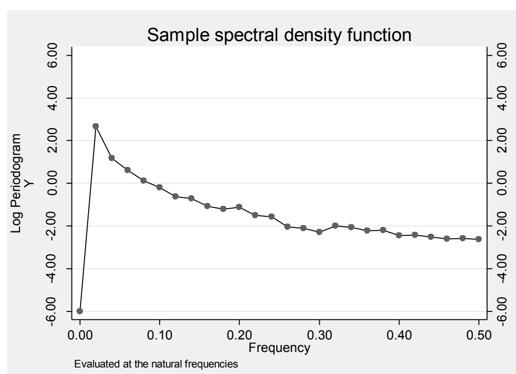
Diagram IV-

Periodograms of Aggegate output (Y) in natural frequencies

Sector 1

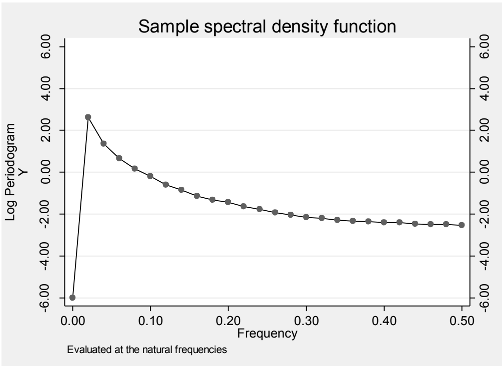


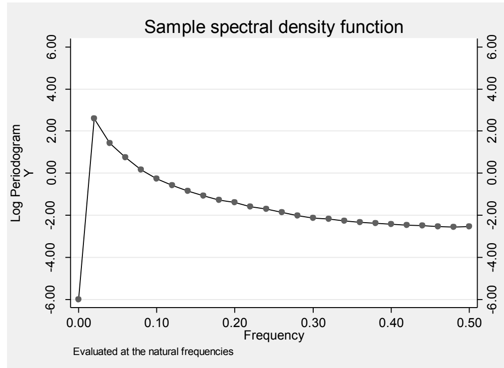
Sector 2



Sector 3

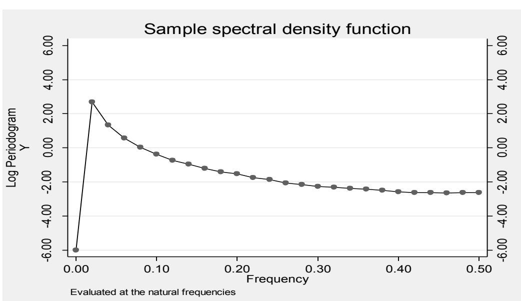
Sector 4

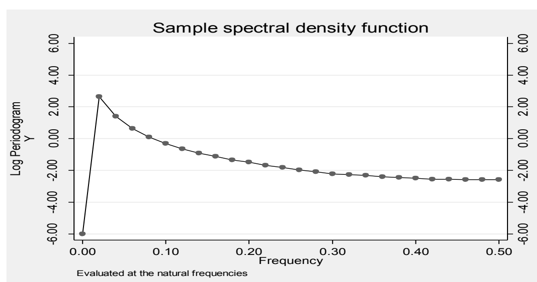




Sector 5

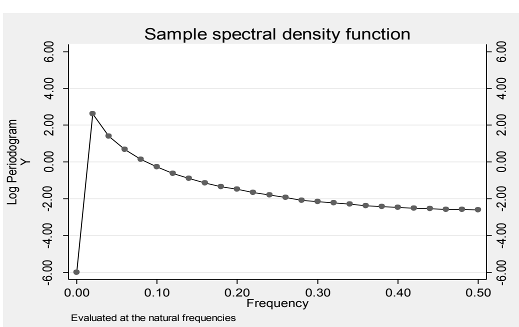
Sector 6

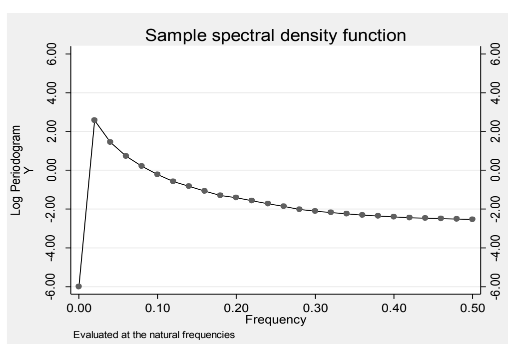




Sector 7

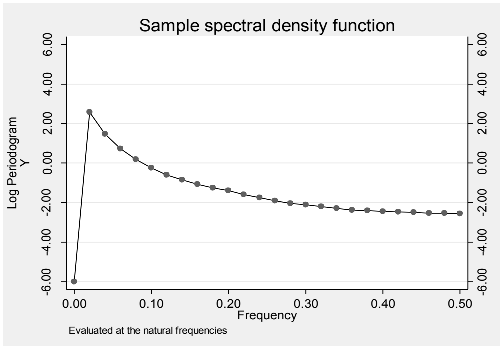
Sector 8

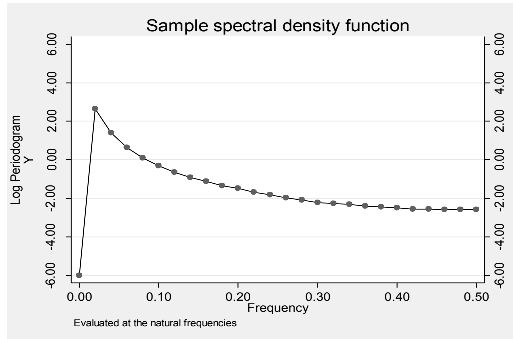




Sector 9

Sector 10





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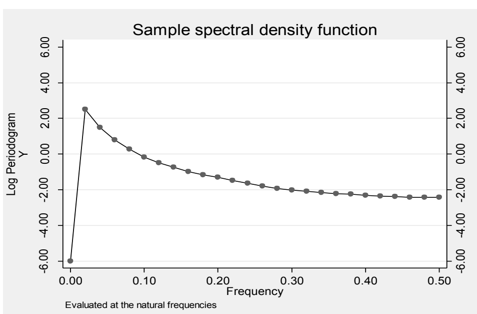

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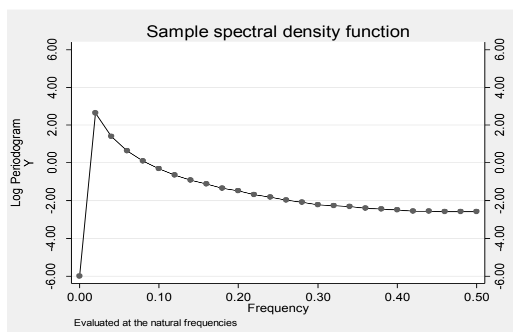

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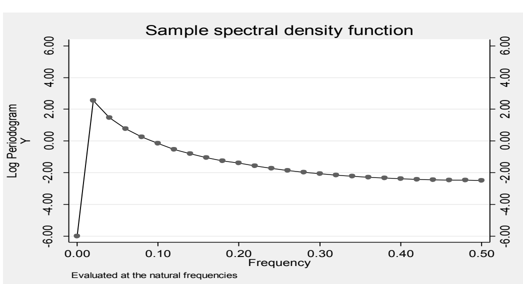

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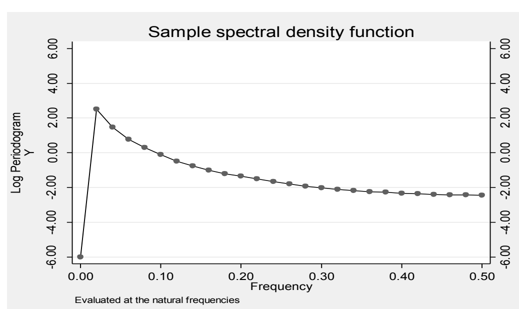


Table V- Johansen Test for Cointegration rank ($\leq k$)

Sector 1			Osterwald -Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	71,13	73,57	15,67	19,96	No
1	2,44	2,44	9,24	9,24	Yes

Sector 2			Osterwald-Lenum		Coint
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	116,47	116,5	15,67	19,96	No
1	0,02	0,02	9,24	9,24	Yes

Sector 3			Osterwald-Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	227,54	227,6	15,67	19,96	No
1	0,06	0,06	9,24	9,24	Yes

Sector 4			Osterwald-Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamdas tatistics	Tracesta tistics	
0	194,11	206,43	15,67	19,96	No
1	8,73	8,73	9,24	9,24	Yes

Sector 5			Osterwald-Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	164,15	164,15	15,67	19,96	No
1	0,01	0,01	9,24	9,24	Yes

Sector 6			Osterwald-Lenum		Coint
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	233,02	234,45	15,67	19,96	No
1	1,43	1,43	9,24	9,24	Yes

Sector 7			Osterwald-Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	254,77	265,55	15,67	19,96	No
1	9,21	9,21	9,24	9,24	Yes

Sector 8			Osterwald-Lenum		Coint
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	253,21	270,21	15,67	19,96	No
1	8,32	8,32	9,24	9,24	Yes

Sector 9			Osterwald-Lenum		**Coint**
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	215,02	215,81	15,67	19,96	No
1	0,96	0,96	9,24	9,24	Yes

Sector 10			Osterwald-Lenum		Coint
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	219,33	221,18	15,67	19,96	No
1	1,71	1,71	9,24	9,24	Yes

Sector 11			Osterwald-Lenum		Coint
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	177,15	177,19	15,67	19,96	No
1	0,05	0,05	9,24	9,24	Yes

Sector 12			Osterwald-Lenum		**Coint**
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	236,3	243,71	15,67	19,96	No
1	7,41	7,41	9,24	9,24	Yes

Sector 13			Osterwald-Lenum		**Coint**
H0: r≤k	MaxLamda statistic	Tracest atistic	MaxLamda statistic	Tracest atistic	
0	270,35	276,23	15,67	19,96	No
1	5,96	5,96	9,24	9,24	Yes

Sector 14			Osterwald-Lenum		**Coint**
H0: r≤k	MaxLamdas tatistic	Tracesta tistic	MaxLamdas tatistic	Tracesta tistic	
0	247,11	249,12	15,67	19,96	No
1	2,43	2,43	9,24	9,24	Yes

Tables VI&VII – Speed(α) and level (β) of Equilibrium Convergence between Aggregate Output (Y) and R&D (R)

Table IV-Aggregate Output (Y)			
Sectors	A	β	α*β
1	4,12	0,03	0,12
2	0,06	0,01	0,00
3	0,06	-0,01	0,00
4	10,15	-0,03	-0,30
5	0,01	0,01	0,00
6	3,52	-0,01	-0,04
7	15,45	-0,01	-0,15
8	13,44	-0,08	-1,08
9	1,01	-0,01	-0,01
10	4,31	-0,01	-0,04
11	0,06	-0,01	0,00
12	3,95	-0,01	-0,04
13	0,55	-0,01	-0,01
14	2,31	-0,01	-0,02

Table V-R&D expenses (R)			
Sectors	α	β	α*β
1	86,12	0,03	2,58
2	0,03	0,14	0,00
3	-0,02	2,81	-0,06
4	-0,56	1,19	-0,67
5	0,03	0,03	0,00
6	-4,33	0,03	-0,13
7	-0,52	0,46	-0,24
8	-0,94	0,49	-0,46
9	-2,36	0,03	-0,07
10	-0,41	0,23	-0,09
11	-0,28	0,01	0,00
12	-0,16	2,62	-0,42
13	-47,14	0,07	-3,30
14	-0,17	0,51	-0,09

Tables VIII &IX- Granger causality

Table VIII

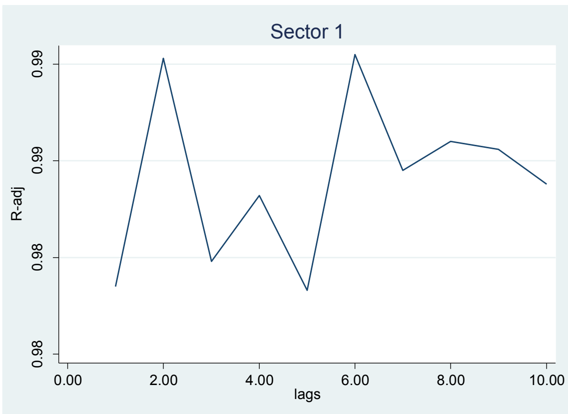
R&D does not Granger cause Aggregate output (Y)				
Sectors	FPE criteria	obs	F-stat	p-value
1	10	40	30.92	0
2	9	41	4.48	0
3	8	42	7.69	0
4	10	40	12.97	0
5	4	46	1.56	0.20
6	10	40	2.51	0.04
7	5	45	6.69	0.04
8	9	41	2.28	0.02
9	10	40	2.65	0.03
10	9	41	6.42	0
11	3	47	6.14	0.01
12	7	43	7.58	0
13	10	40	1.39	0.25
14	8	42	3.80	0.01

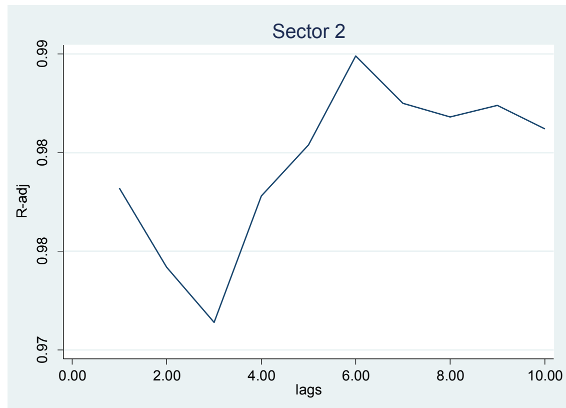
Table IX

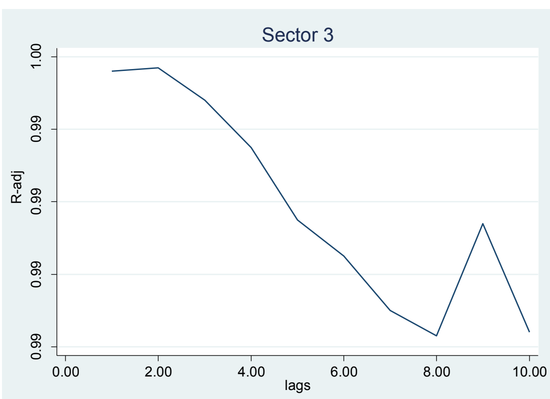
Aggregate output (Y) does not Granger cause R&D				
Sectors	FPE criteria	obs	F-stat	p-value
1	1	49	4.99	0.02
2	2	48	15.38	0
3	8	42	3.96	0.01
4	5	45	2.53	0.07
5	2	48	1.52	0.23
6	1	49	17.13	0
7	8	42	10.86	0
8	3	47	17.17	0
9	6	44	18.89	0
10	6	44	3.25	0.01
11	3	47	6.00	0.01
12	3	47	15.80	0.29
13	6	44	2.37	0.06
14	3	47	2.29	0.09

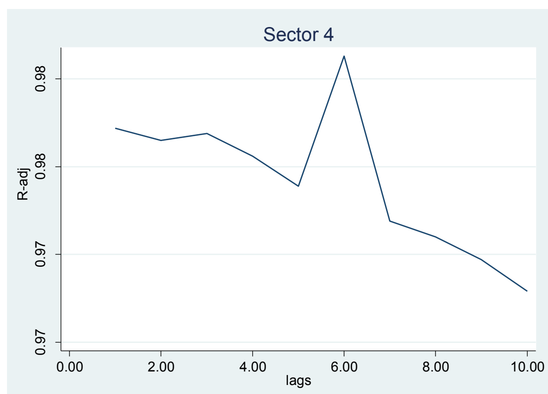
Diagram X

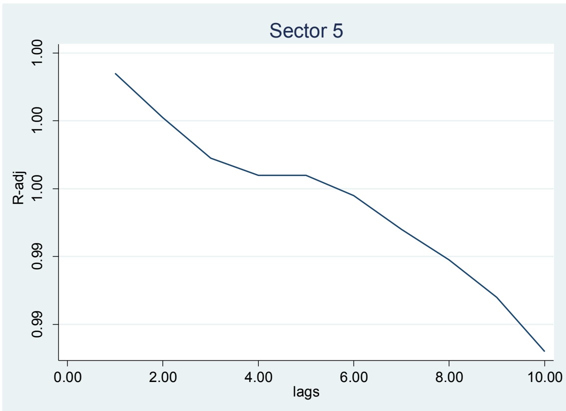
Stepwise causality (Duffour-Renault test)- R&D (R) expenses cause Aggregate output (Y) evalution through maximum R^2-adj.

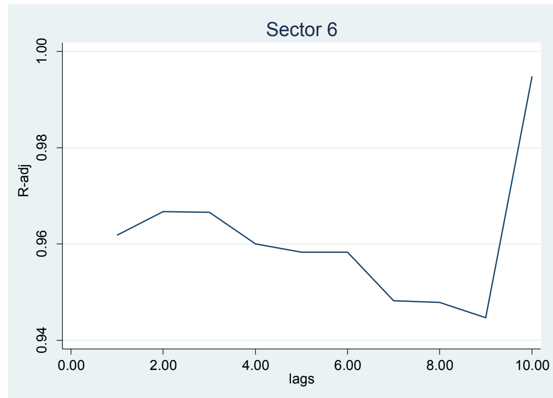


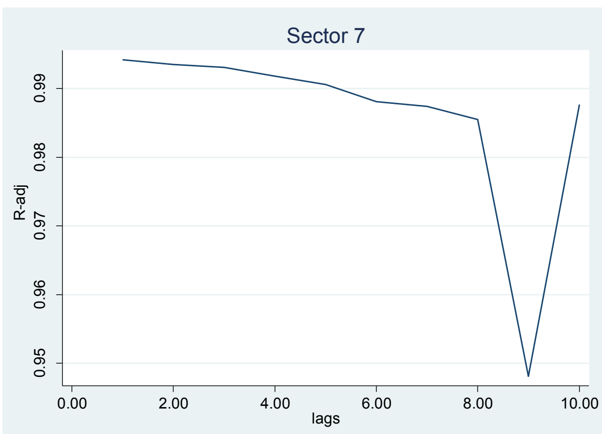


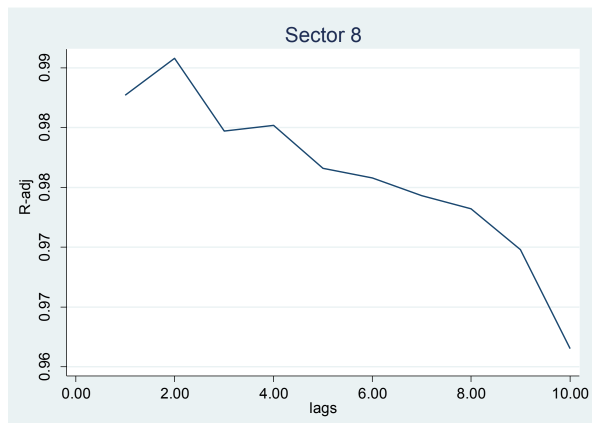


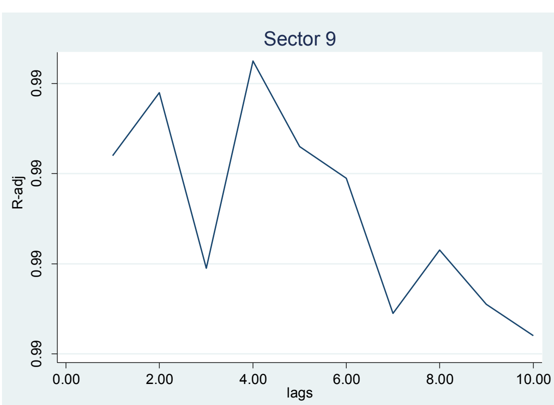


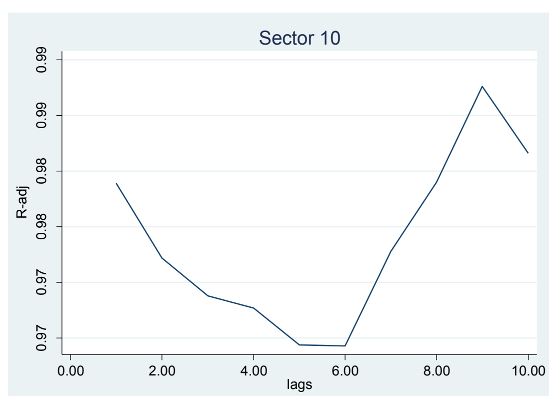

Sector 5
R-adj
1.00
1.00
1.00
0.99
0.99
0.00 2.00 4.00 6.00 8.00 10.00
lags

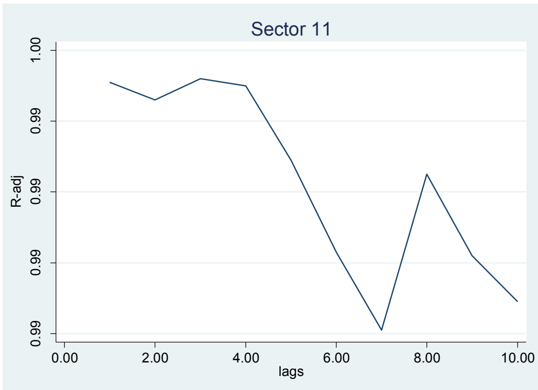

Sector 6
R-adj
1.00
0.98
0.96
0.94
0.00 2.00 4.00 6.00 8.00 10.00
lags

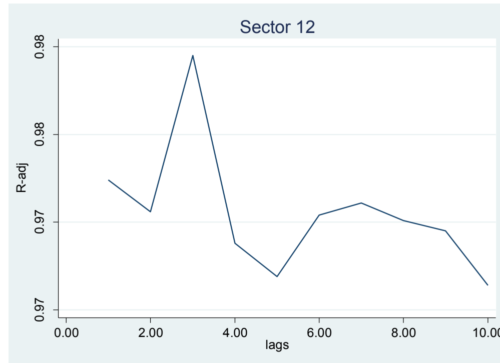

Sector 7
R-adj
0.99
0.98
0.97
0.96
0.95
0.00 2.00 4.00 6.00 8.00 10.00
lags

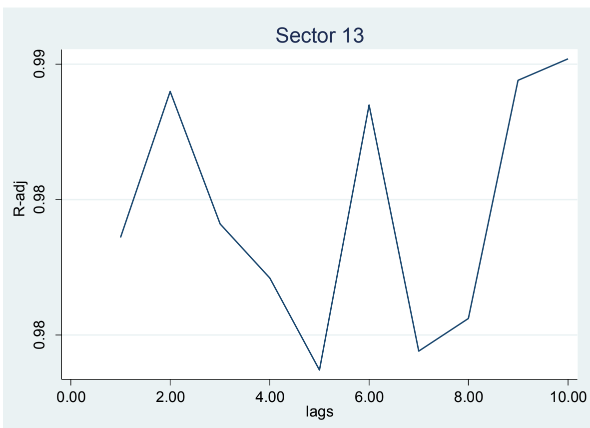

Sector 8
R-adj
0.99
0.98
0.98
0.97
0.97
0.96
0.00 2.00 4.00 6.00 8.00 10.00
lags


Sector 9
R-adj
0.99
0.99
0.99
0.99
0.00 2.00 4.00 6.00 8.00 10.00
lags


Sector 10
R-adj
0.99
0.99
0.98
0.98
0.97
0.97
0.00 2.00 4.00 6.00 8.00 10.00
lags







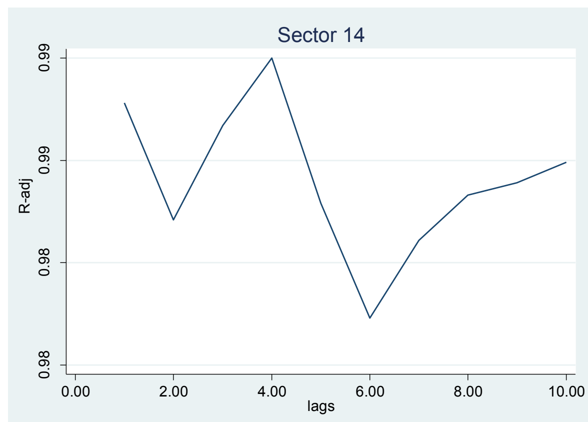
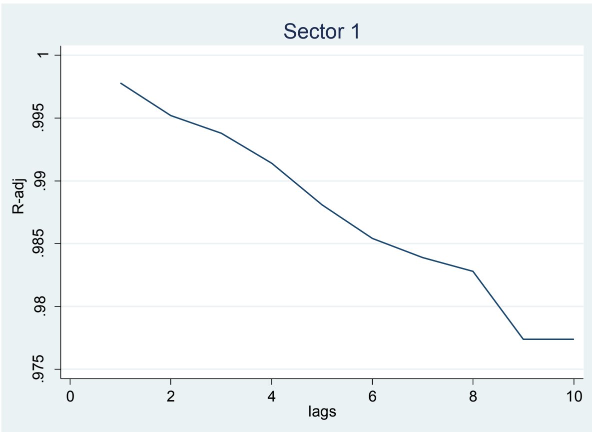
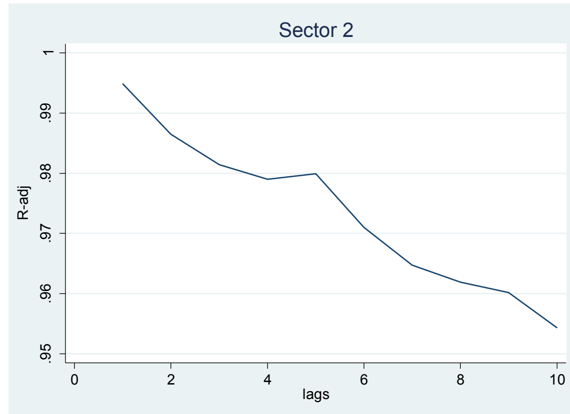
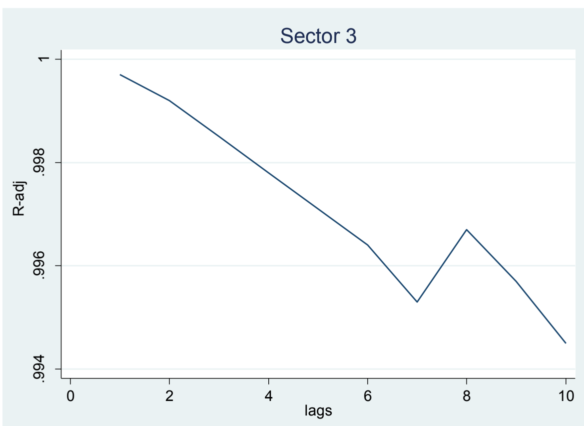


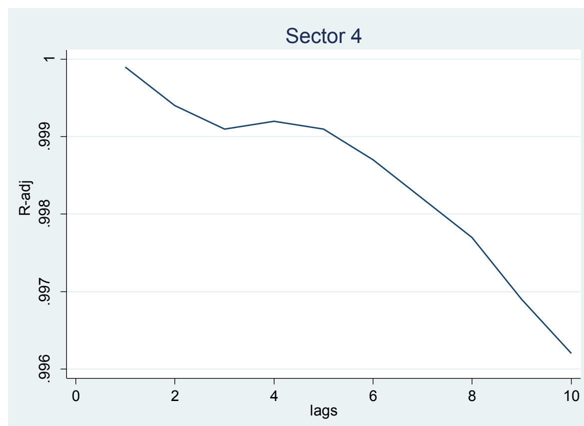
Diagram XI

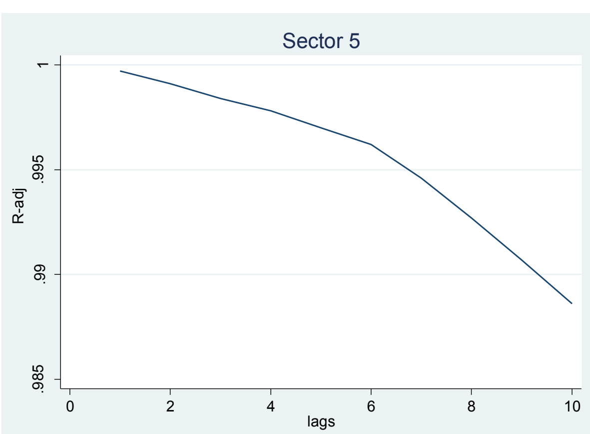
Stepwise causality (a la Duffour-Renault)- Aggregate output (Y) cause R&D expenses (R) evalution through maximum R^2-adj.

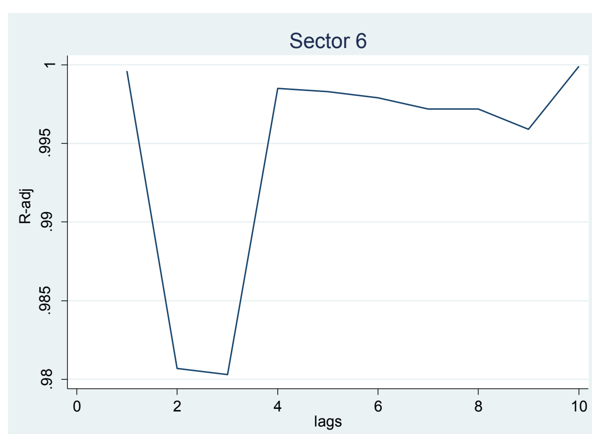

Sector 1
R-adj
.975
.98
.985
.99
.995
1
0
2
4
6
8
10
lags

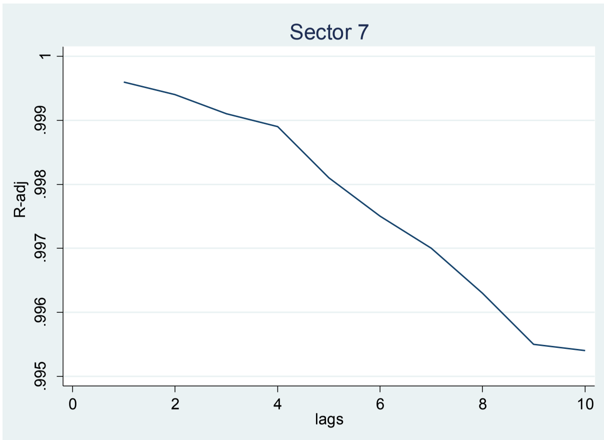

Sector 2
R-adj
.95
.96
.97
.98
.99
1
0
2
4
6
8
10
lags


Sector 3
R-adj
.994
.996
.998
1
0
2
4
6
8
10
lags

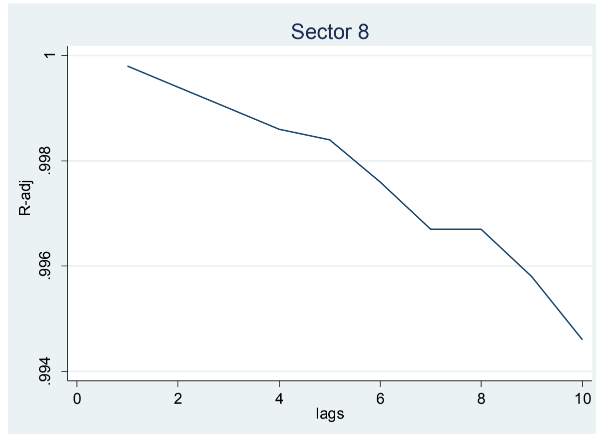

Sector 4
R-adj
.996
.997
.998
.999
1
0
2
4
6
8
10
lags


Sector 5
R-adj
.985
.99
.995
1
0
2
4
6
8
10
lags

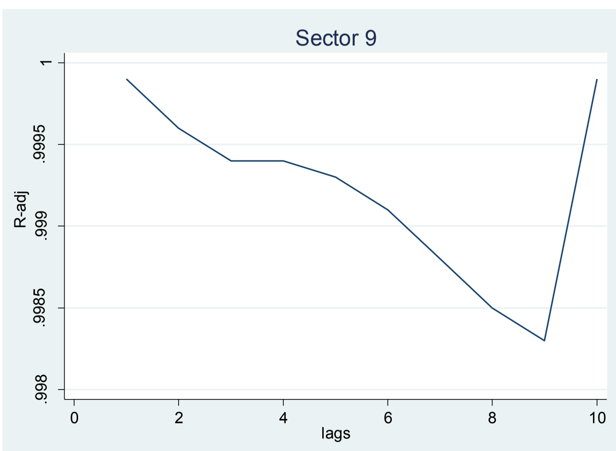

Sector 6
R-adj
.98
.985
.99
.995
1
0
2
4
6
8
10
lags



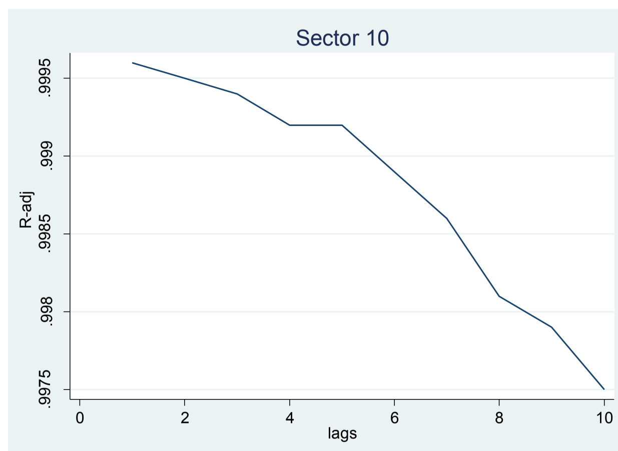
Sector 7
R-adj
lags



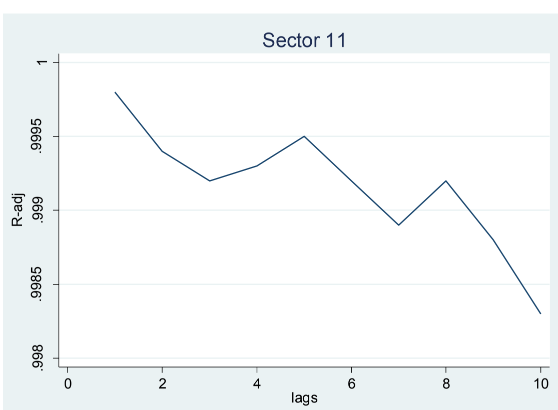
Sector 8
R-adj
lags



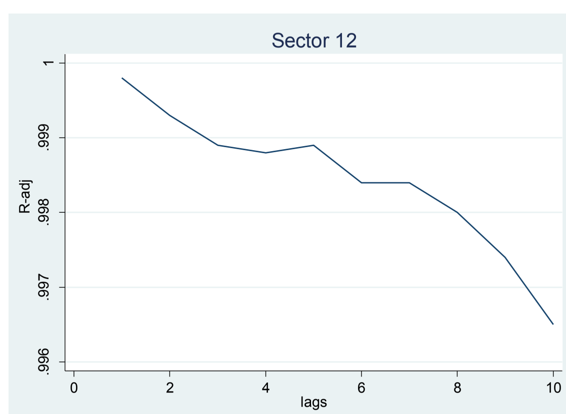
Sector 9
R-adj
lags



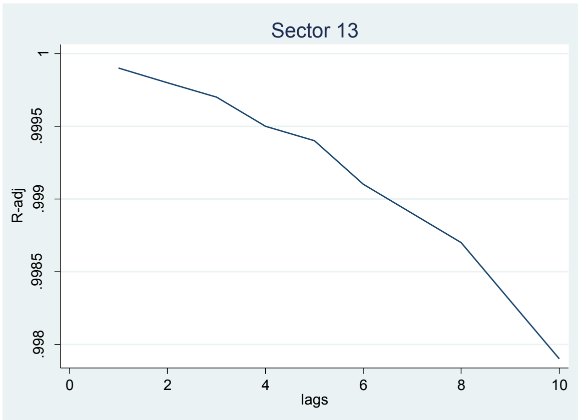
Sector 10
R-adj
lags



Sector 11
R-adj
lags



Sector 12
R-adj
lags


Sector 13
R-adj
1
.9995
.999
.9985
.998
0
2
4
6
8
10
lags

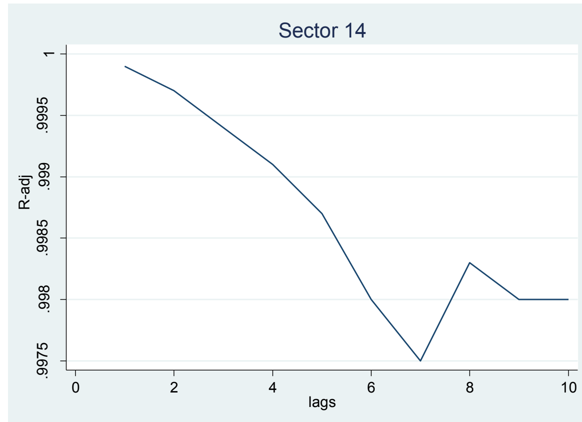

Sector 14
R-adj
1
.9995
.999
.9985
.998
.9975
0
2
4
6
8
10
lags

Table XII- Industry Classification

Table XII				
	INDUSTRIAL SECTORS (U.S. ECONOMY)			
SECTO RS	**DESCRIPTION**	**NACE CLASSIFICATION**	**VARIABLES AVAILABLE**	**SOURCE**
1	AGRICULTURE,FORESTRY AND FISHING	A01,A02,A03	OUTPUT (Y)	National Bureau of Economic Activity
2	MINING, PETROLEUM AND COAL PRODUCTS	B, C10-C12, C13-C15, C16, C17, C18, C19, C20,C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, C31-C32, C33		
3	ELECTRICITY, GAS AND WATER	D,E36,E37-E39		
4	CONSTRUCTION	F		
5	FOOD & BEVERAGES, WOOD PRODUCTS AND FURNITURE, METAL PRODUCTS	I		
6	WHOLESALE TRADE	G45,G46		
7	RETAILTRADE	G47		
8	TRANSPORT AND STORAGE	H49,H50,H51,H52,H53		
9	INFORMATION&TECHNOLOGY INDUSTRY	J58,J59-J60,J61,J62-J63,S95	R&D EXPENSES	National Scientific Foundation of the U.S
10	REAL ESTATE AND BUSINESS SERVICES,FINANCE AND INSURANCE	K64,K65,K66,L,L68A,M71, M72,N77		
11	COMMUNICATION SOCIAL AND PERSONAL SERVICES	M73, M74-M75, N79, N80-N82, O, Q87-Q88, R90-R92, R93, S94, S96, T, U		
12	BUSINESS MANAGEMENT SERVICES	M69-M70,N78		
13	EDUCATIONAL ORGANIZATIONS	P		
14	HEALTH SERVICES	Q86		

APPENDIX B. Econometric Appendix

ADF test

In this paper, we use the popular Augmented Dickey-Fuller (ADF) methodology (Dickey and Fuller, 1979) to test for stationarity. The ADF test is based on the following model (Kaskarelis, 1993):

$$\Delta \mathrm{Y}_t = \alpha + bt + \rho Y_{t-1} + \sum_{i=1}^{m} \gamma_\iota \Delta \mathrm{Y}_{t-1} + \varepsilon_\tau$$

whereΔ is the first difference operator, t the time and ε the error term:

(a) if $b\neq 0$ and $-1<\rho<0$ implies a trend stationary model;

(b) if $b=0$ and $-1<\rho<0$ implies an ARMA Box/Jenkins class of models;

(c) if $b=0$ and $\rho=0$ implies a difference stationary model where Y variable is integrated of degree one I(1). If we assume that the cyclical component is stationary, the secular component has a unit root and Y follows a random walk process, i.e. it revolves around the zero value in a random way (Heyman and Sobel, 2004, 263); furthermore, if a $\neq 0$ Y follows a random walk process with a drift.

Spectral Analysis-Periodograms

Using the standard notation, a periodogram is a graph of the spectral density function of a time series as a function in the frequency domain. The function has the following form:

$$f(\omega) = (1/\pi)\sum_{k=-\infty}^{\infty} \gamma_k e^{-ik\omega} = (1/\pi)\gamma_0 + (2/\pi)\sum_{k=1}^{\infty} \gamma_k \cos(\omega k)$$

The dynamics of the above Fourier transformation is that it first standardizes the amplitude of the density by the sample variance of the time series, and then plots the logarithm of that standardized density.

Cointegtration Test

In technical terms, in the presense of cointegration between the variables, Error Correction Terms have to be employed in the implementation of Granger causality tests. To this end, we employ the popular Johansen (1988) methodology that allows for more than one cointegrating relationship, in contrast to other relevant tests. The methodology is based on the following equation:

$$\Delta y_t = m + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_\iota \Delta y_{t-i} + e_p$$

$$where \Pi = \sum_{\iota=1}^{p} A_i - I \; and \Gamma_i = -\sum_{j=i+1}^{p} A_p$$

The existence of cointegration depends upon the rank of the coefficient matrix Π, which is tested through the two likelihood ratios, namely the trace test and the maximum eigenvalue test, respectively, described by the following formulas:

$$\begin{Bmatrix} J_{trace} = -T \sum_{i=r+1}^{k} \log(1-\lambda_i) \\ J_{\max} = -T \log(1-\lambda_i) \end{Bmatrix}$$

where T is sample size and λ_i is the largest canonical correlation.

The trace test tests the null hypothesis of $r \leq n$ cointegrating vectors, whereas the maximum eigenvalue test, tests the null hypothesis of $r \leq r+1$ cointegrating vectors and the critical values are found in Johansen and Juselius (1990).

Granger Causality testing

The concept of causality, introduced by Granger (1969), has been widely used in *Economics*. In general, we say that a variable X causes another variable Y if past changes in X help to explain current change in Y with past changes in Y. The concept of causality, introduced by Granger (1969), has been widely used in economics. In general, we say that a variable X causes another variable Y if past changes in X help to explain current change in Y with past changes in Y. Of course, the general autoregressive model is appropriate for testing Granger causality only if the variables are not cointegrated. As we have seen, cointegration implies that two or more variables have a long-run equilibrium relationship. Granger (1986) and Engle and Granger (1987) suggested a test based on cointegration and error-correction models. If cointegration is not detected, the autoregressive model is estimated.

The empirical investigation of (Granger) causality is based on the following general autoregressive model (Engle and Granger 1987):

$$\Delta Y_t = a_0 + \sum_{i-1}^{m} a_{1i} \Delta Y_{t-i} + \sum_{i=0}^{n} a_{2i} \Delta X_{t-i} + \lambda_i \mu_{t-1} + \varepsilon_t$$

whereΔ is the first difference operator, ΔY and ΔX are stationary time series and ε_t is the white noise error term with zero mean and constant variance. Also, μ_{t-1} is the lagged value of the error term of the co-integration regression: $Y_t = c_1 + c_2 X_t + \mu_t$through which causality could emerge. The aforementioned model is appropriate only when co-integration is detected. If the variables are not co-integrated, the previous model is estimated without the $\lambda\mu_{t-1}$ term. The null hypothesis that X does not Granger-cause Y is rejected if the coefficient α_{2i} is statistically significant. Various lag lengths are tested. In order to identify the optimal lag length, we use the Akaike information criterion (AIC) and the final prediction error (FPE) criteria (Thornton and Batten, 1985; Gutierrez et al., 2007; Hsiao, 1981; Ahking and Miller, 1985; Khim and Liew, 2004; Hacker and Hatemi-J, 2008).

Short-run Causality

Base on Dufour and Renault (1998) and Dufour et *al.* (2006) the test of the hypothesis that variable *y (t)* is not causal for variable *x (t)* at horizon *h=1, 2,…* is now based on the following model :

$$x_{i,t} = a_i + c_i x_{it+h} + b_i y_{i,t+h} + u_{i,t+h} \forall h \; 1,2, \dots \mathrm{H}$$

For $\mathrm{i} = 1, \dots 14$ and$\mathrm{t} = 1, \dots, \mathrm{T}$where: $x_{i,t}, y_{i,t}$ are the variable vectors under investigation; c_i is the lag coefficients of x_{it}; a_i is a vector of fixed intercept andb_i is the lag coefficient of the variable $y_{i,t}$.

The null hypothesis of no causality at time horizon h implies that the vector of coefficients b_i of the variables $y_{i,t}$ for each sector $\mathrm{i} = 1,2,\dots 14$ for the variablesx_{it} are such that b_{ij}=0, $\forall \mathrm{j} \neq \mathrm{h}$, $\mathrm{j} \in \{1,, \dots \Omega_i\}$ for each sector i=1,2,...14 which can be routinely tested. Also, if $y_{i,t}$ is not causal for $x_{i,t}$ at time horizon h^* then this is also the case for all $h > h^*$.