PATENT ACTIVITY IN THE POLISH FOOD SYSTEM AND THE BUSINESS CYCLE. CONCLUSIONS FROM SPECTRAL ANALYSIS

Justyna KUFEL-GAJDA [ID][1][✉], Janusz GAJDA [ID][2]

[1]*Department of European Integration, Institute of Rural and Agricultural Development Polish Academy of Sciences, Warsaw, Poland*
[2]*Faculty of Economic Sciences, University of Warsaw, Warsaw, Poland*

Abstract. Invention activity is an important innovation development factor, as it not only imposes changes in economic activity, but also often leads to the completely new structures within sectors. The aim of the paper was to investigate the relationship between macroeconomic and sectorial business cycle, and the patent filings in the food system in Poland in the period 2006–2022 taking advantage of statistics defined in time and frequency domains. Data on patent applications from 34 IPC classification (sub-)classes were analyzed, combined into five groups: food, beverages, tobacco, agricultural chemistry, agricultural machinery and packaging. The results obtained with spectral and cross-spectral analysis tools were compared with results obtained in the time domain. The positive relationship between patents and macroeconomic cycle is the strongest for cycles lasting 3.5–4 years, which dominate in reference to GDP series in the analyzed period. Patent filings are strongly positively correlated also with the agri-food sector output, especially in shorter cycles of 2.5–3 years. Although cycles of patent filings fluctuate much more than both business cycles, they seem to be more similar to the agri-food sector fluctuations. Moreover, patent activity may be treated as an early warning indicator of sectorial economic activity, whereas it's lagging in reference to the aggregated economic activity.

1. Introduction

Patents, together with copyrights, trademarks, awards and government grants, are enumerated as exogenous incentives for innovation, which are related mostly to the government activities aiming at encouraging innovation (Carlton & Perloff, 2005). The objective of a patent is to provide an investor with exclusive rights to a new and useful product, process, substance or project. As rational investors involve in expensive research until the expected marginal revenue is equal to marginal cost, patents allow them to capture a large share of profit from producing new knowledge through isolating from competition. Guaranteeing the exclusive right, the society encourages more inventions, because the estimate private rate of return on the R&D activity is smaller than the social one (Jones & Williams, 1998; Mansfield, 1998). Only some people make innovations for their own good or for the good of humanity. Most do this for cash prizes, and when there is no patent protection, fewer innovations are created

and anybody can copy them. Imitations increase the level of competition and the price is reduced to the competitive level (Figiel et al., 2017).

As incentives for innovation, patents are the object of interest among researchers studying business cycles. In the latest study Othmani et al. (2023) show that in the short-term economic growth cause patent, not vice versa, and there is no causal relationship between them in the long term, concluding that patents can't be regarded as source of economic growth. Miranda-Agrippino et al. (2024), on the other hand, taking advantage of data on patent applications to recover technology news shocks, found that even if they have no effect on aggregate productivity in the short run, they are a significant driver of its trend component. Analyzing trends was interesting especially in reference to results obtained by Hingley and Park (2017), who were studying the sensitivity of the data on patent filings delivered by the European Patent Office to the business cycle, used the detrended series and showed that forecasts relying only on trends are less accurate in predicting economic downturns and upturns.

The relationship between innovations and the business cycle has a long and interesting history. According Schumpeter (1939), Hall (1991), Caballero and Hammour (1994), Aghion et al. (2012) the innovation activity is countercyclical, as creative destruction occurs during recessions. One of explanations is that the opportunity cost of investing in the growth of productivity is lower during downturns, what encourages innovativeness (Aghion & Saint-Paul, 1998; Cooper & Haltiwanger, 1993). On the contrary to the theory, the empirical studies, starting from Griliches (1984) and ending up on Howell et al. (2023), shows that the innovation activity behaves procyclically.

The literature strictly on the relationship between patenting and the business cycle is rather limited. Instead on patenting, more interest is put on Research and Development (R&D) expenditures, on proxy variables like credit constraints or sales declines, as well as on comparing conditions before and after the recession. Scientists are especially interested if significant shocks in the economy affect patenting, like oil shocks (Griliches, 1990) or 2008–2009 crisis (European Commission, 2011; Guellec & Wunsch-Vincent, 2009; Organization for Economic Cooperation and Development [OECD], 2009; World Intellectual Property Organization [WIPO], 2010).

In general the mutual relationship between patenting and the business cycle is explained from the two perspectives – effects of innovation activity on the business cycle and vice versa. In the first perspective patents are perceived as a key factor for the economic development because of its impact on productivity, and changes in patenting are treated as a technology shock to economy. Miranda-Agrippino et al. (2023) made a broad and detailed overview of the empirical literature on the impact of technology news shock on the economy, although the history of treating the applications of technology news as a source of economic fluctuations is rather short (Beaudry & Portier, 2014).

In the second perspective two kinds of effects are distinguished – resource effect and opportunity cost effect (Hingley & Park, 2017). According to the first one, during upturns companies have broader access to resources financing research projects, both internal (cash flow, retained earnings) and external (venture capital, subsidies and grants from public sector), and this effect makes innovation procyclical. The second effect makes innovation countercyclical because of the lower cost of conducting R&D during recessions (lower prices of materials

and labor) and lower opportunity cost during recessions – innovation needs changing the allocation of resources and effort from production and marketing to innovation processes, and during recessions the sales loss is not so high as in upturns.

Depending on the data source, the relationship between the innovation activity and the business cycle may be measured on the microeconomic (industry or firm data) or macroeconomic (country data) level. Regarding the first group, results of the majority of studies indicate that innovation is procyclical, e.g., Rafferty and Funk (2008) revealed weak opportunity cost effect, Martinsson and Lf (2009) indicated that patenting is procyclical only during downturns, Giedeman et al. (2006) showed that patenting is procyclical in high-tech goods of low durability and countercyclical in other durable consumer goods, while Geroski and Walters (1995) pointed out that successful innovations are procyclical. On the contrary, Lopez-Garcia et al. (2012) showed that without credit constraints during downturns companies invest in R&D and trainings, making it countercyclical. Also in the majority of macroeconomic analyses little evidence is found for the opportunity cost effect (e.g. European Commision, 2011; Guellec & Wunsch-Vincent, 2009; Hingley & Park 2017; OECD, 2009; WIPO, 2010;).

Understanding how a patent activity changes is especially important for patenting institutions, like national and international patent offices, that based on patent forecasts plan budgetary and resource allocations, but also for legal and consulting service operators, who support the system. The patent activity may influence investment and marketing decisions of patentees, and consequently make a feedback effect on the innovation and commercialization activity (Meade & Islam, 2006).

The modern literature examines the cyclical components of time series (e.g. Hingley & Park, 2017; Gradzewicz et al., 2010; Skrzypczyńska, 2014; Othmani et al., 2023), but in the past in accordance with the economic growth theory, it concentrated mostly on changes in absolute values, structural determinants, trend factors and patents as drivers of long-term productivity and technological change (e.g. Danguy et al., 2014; De Rassenfosse & van Pottelsberghe de la Potterie, 2007, 2012; Hall, 2005; Hu & Jefferson, 2009;; Kortum & Lerner, 1998; Liu et al., 2014; Park, 1999; Sanyal & Jaffe, 2005; Scherer, 1983; Thumm, 2001). The problem is that from one side innovation projects are long-term and last longer than market cycles (Heger, 2004), but from the other side – short-term resource constraints (during recessions) may influence patenting behavior, as it is an expensive process, which costs must be paid before commercialization.

In this framework the aim of the paper is to investigate the character of the relationship between patent activity in the food system and the business cycle in Poland, both on the macroeconomic and the sectorial levels. We ask four research questions regarding invention activity in the Polish food system:

1. How intense was the patent activity in the Polish food system in the period 2006–2022, how was it changing, which food system areas, sections and actors were the most active?

2. Does patent activity behave procyclically, countercyclically or acyclically in regard to the macroeconomic and the sectorial business cycles?

3. Is the patent activity a simultaneous, leading or lagging business cycle indicator?

4. Are the patent activity fluctuations similar to economic activity fluctuations?

Interestingly, Howell et al. (2023) showed that companies backed by venture capital have higher quality and economic importance than those in the broader economy, and their patent activity is more procyclical. The rationale is that during recessions venture capitalists shift funding to less innovative, but more profitable companies, which facing challenging environment need more financing. As the most economically important innovations amplify the procyclicality of innovation, we think that the food system will counter the procyclicality. Consequently, the hypothesis is that along with the theory of Schumpeter the invention activity in the food industry changes countercyclically, and anticipates the business cycle, being a leading business cycle indicator.

For years the agri-food sector was perceived as the most traditional and the least innovative. During the last few years "the agri-food sector" has been more and more often replaced by the expression "food system" or "sustainable food system". After Food and Agriculture Organization [FAO] (2018), the food system encompasses not only production, aggregation, processing, distribution, consumption and disposal of food products produced in agriculture, forestry and fisheries, but also their economic, societal and natural environments. Consequently, in the food system technologies supporting traditional agri-food activities become more important, which are fertilizers and raw materials for agriculture, agricultural machines and equipment, packaging, storage and delivery technologies, as well as technologies of processing waste from food production and consumption.

Changing of perspective in looking at the food system has its roots in the challenges like increasing population, urbanization, wealth, changing patterns of consumption, but also climate change and decreasing natural resources. Development of the food industry helped producers and consumers, being a source of many off-farm employment opportunities and giving to consumers more choices regarding terms, form and quality of food. But it brings also many negative consequences. Highly processed food of high calories and low nutrition values is now widely available. The access of small producers and agri-enterprises to the market is limited. Food loss and waste are contently increasing. Longer and more industrialized food chains use more energy, and it is more difficult and complicated to assure food safety.

Not only FAO understood the significance of transition to sustainable food systems. Also United Nations , European Commission, OECD, Science Advice for Policy by European Academics [SAPEA] and many other institutions and research bodies on the international and national levels participate now in the discussion, plan and act in the field (United Nations, 2022; Standing Committee on Agricultural Research [SCAR], 2021, 2023; OECD, 2021; SAPEA, 2020). But what is happening in the food industry? How does this political pressure on producing more healthy food affect it? Does it translate into higher or lower innovativeness of the sector? From one side food products should be simpler and food chains shorter, from the other each transition needs innovations, which become the new regime.

There are many studies on innovativeness, R&D activity and patenting in the agri-food sector (e.g., Amantae et al., 2024; Barragán-Ocaña et al., 2023; Calafat-Marzal et al., 2023; Chaparro-Banegas et al., 2024; Fairbairn et al., 2022; Ponta et al., 2022). The situation in the Polish agri-food sector was analyzed by Baczko et al. (2008) and Klincewicz (2019). In the period 2020–2022, 25.9% of Polish enterprises manufacturing food products implemented innovations. 22.3% of the innovations concerned business processes innovations, and only

11.5% – product innovations (National Statistical Office, 2023). While more innovations concern technological processes rather than new products, many innovations aim at differentiating or ensuring food safety and therefore are not significant technological modifications, which could be patented. Compared with other branches, the expenditures on R&D activities of the food products and beverages manufacturers are relatively low and they write not many patent filings (Allred & Park, 2007; Avermaete et al., 2004). Surveys of R&D managers from the food industry show also, that they do not perceive patents as instruments effectively protecting innovations against copying (Cohen et al., 2000).

Despite a low level of expenditures on R&D and patenting, many agri-food producers are highly innovative, what is related mainly to increasing the scale of production, improving the existing products and better meeting consumer needs, including personalization and tailoring the offer to the individual needs (Acosta et al., 2015). Harrington (2004) and Albors-Garrigós et al. (2018) noticed also, that innovation in this sector may concern offering new sensory experiences, like culinary innovations. They arise in different processes than classic R&D, can't be patented, but might be easily copied when the knowledge and know-how are not properly protected (Ottenbacher & Harrington, 2007). An important exception is functional food, where there are both classic R&D and technological innovations, as it offers additional health benefits compared to traditional food products (Bigliardi & Galati, 2013). Taking into account new tendencies in the agri-food sector, developing new food products (novel foods) is less popular than assuring food safety, improving food quality, food chains optimization or developing functional food (Santeramo et al., 2018).

As may be expected, agri-food companies are not the only innovators in the food system (Klincewicz, 2019). Food products and food choices are more frequently modified because of political regulations, which aim at making food patterns healthier, e.g., by reducing salt or sugar content (Griffith et al., 2017), or at limiting both promotion and offering of products perceived as unfavorable for consumers (Dubois et al., 2018). Suppliers and distributors of food products are another important innovation sources, especially packaging manufacturers and suppliers of food packaging technologies (Trott & Simms, 2017). Retail chains improve innovativeness by asking and looking for new products, eco-innovations and environmentally friendly solutions (Mylan et al., 2015). Cooperation with companies from other areas of economic activity stimulates the innovations connected with reducing food wastage along the agri-food chains (e.g., Mirabella et al., 2014). Also, the dynamic development of information and telecommunication technologies improves the level of innovativeness of the agri-food sector (Klincewicz, 2019). This includes using mobiles, cloud computing, social media, big data, traceability and blockchain technologies, or Internet of things (Bryceson & Yaseen, 2018).

In this paper we tried to investigate the number and structure of the patent applications in the Polish food system in the period 2006–2022 and the relationship between patent activity in the food system and the business cycle regarded in economics theory as the most important factor influencing this activity. In order to answer the research question firstly the material and methods will be presented. Then the used variables will be characterized, that is economic activity measures as well as the number of patent filings. Afterwards the economic activity and patent filings fluctuations will be illustrated, and the dominant frequency of fluctuations, length of cycles, amplitude of fluctuations and turning points will be determined. In the next

step characteristics of the relationships in the time (correlations, cross-correlations, relative deviations) and frequency domains (dynamic correlations, phase shift, gain, coherence) will be calculated and the results compared. Presenting the results will be followed by their discussion combined with recommendations for policy.

The principal conclusion from the work is that patent filings in the Polish food system are procyclical in reference to both the GDP and the agri-food sector output, as well as they may be treated as a leading indicator of the sectorial economic activity and a lagging indicator of the aggregated economic activity. Moreover, because of much higher amplitude of fluctuations of patent filings than macroeconomic and sectorial business cycles and rather weak similarity between both variables, it might be suspected that the role of patent activity in the business cycle is not so straightforward.

2. Materials and methods

Patent filings is a measure of patent activity and it consists of applying to the Polish Patent Office (PPO) for a patent on an invention, which is an exclusive protective right allowing the use of the invention in a commercial or professional manner on the Polish territory. Data on patent filings were delivered in 2023 by the PPO and prepared according to the International Patent Classification (IPC, version 2012.01). They embrace all first patent filings submitted to the PPO between 1st of January 2006 and 31st of December 2022. The patents may be granted, rejected or the procedure may not be finished yet. Choosing the data on patent filings was in accordance with the aim of the analysis, which was showing the level of technological activity undertaken by inventors and analyze their thematic interests. As some part of patent filings doesn't meet the necessary inventive level and are rejected in the evaluation process, the results may not be used to the assessment of inventiveness nor the intensity of R&D activity. Also, as some granted projects are not commercialized, the results can't be used to the assessment of innovativeness activity (Klincewicz, 2019). From the other side, we focused on total filings send to the PPO, although it is possible that they will be less dependent on business cycle, as they measure the output of earlier research rather than willingness to commercialize (Hingley & Park, 2017). But this is the broader problem when estimating the relationship between patenting and business cycle, that the costs of innovation and patenting are front-loaded while the returns are back-loaded.

As we wanted to embrace not only the food and beverages manufacturing, but the food system, after Klincewicz (2019) we include technologies supporting traditional agri-food activity. Consequently, we analyze the data on patent filings from 34 IPC (sub-)classes divided into six thematic groups (Table 1). They can be connected with certain sections of the Polish Classification of Activities (PCA), what enables analyzing economic fluctuations in the food system. Linking data on patents with data on economic activity was performed in accordance with the European Patent Office recommendations (Van Looy et al., 2014) and based on the literature, e.g., Schmoch (2008), Lybbert and Zolas (2014), Okoń-Horodyńska et al. (2012). The patent filings regarding the following technological areas were analyzed: Food, Beverages, Tobacco, Agrochemistry, Machinery and Packaging. Particularly, the last group includes packaging, their production methods and devices used for their production. Unfortunately, it

doesn't have an equivalent in the PCA, and it includes technologies used in various activities, not only those related with the agri-food sector. Methodological and legal aspects of patents in the agri-food sector in Poland were described by Baczko (2018), Wisła (2018), Suchoń (2010). Our dataset was also divided according to the type of entity of the first patent applicant (physical person, economic sector entity, university, research institute, Polish Academy of Sciences entity). Applications made by international entities weren't therefore taken into account, so the analysis of the relationship between patent filings and economic activity in Poland isn't burdened.

Table 1. (Sub-)classes of inventions according to the International Patent Classification (IPC, version 2012.01) chosen for the analysis and their links to sections of the Polish Classification of Activities (PCA) based on NACE – the Statistical Classification of Economic Activities in the European Community

	"Food" – manufacture of food products (PCA 10)
A01H	New plants or processes for obtaining them; plant reproduction by tissue culture techniques
A01J	Manufacture of dairy products
A21D	Treatment, e.g., preservation, of flour or dough for baking, e.g., by addition of materials; baking; bakery products; preservation thereof
A23B	Preserving, e.g., by canning, meat, fish, eggs, fruit, vegetables, edible seeds; chemical ripening of fruit or vegetables; the preserved, ripened, or canned products
A23C	Dairy products, e.g., milk, butter, cheese; milk or cheese substitutes; making thereof
A23D	Edible oils or fats, e.g., margarines, shortenings, cooking oils
A23F	Coffee; tea; their substitutes; manufacture, preparation, or infusion thereof
A23G	Cocoa; cocoa products, e.g., chocolate; substitutes for cocoa or cocoa products; confectionery; chewing gum; ice-cream; preparation thereof
A23J	Protein compositions for foodstuffs; working-up proteins for foodstuffs; phosphatide compositions for foodstuffs
A23K	Feeding-stuffs specially adapted for animals; methods specially adapted for production thereof
A23L 1	Food or foodstuffs – preparation or processing
A23L 3	Preservation of foods or foodstuffs, in general, e.g., pasteurising, sterilising, specially adapted for foods or foodstuffs
A23P	Shaping or working of foodstuffs, not fully covered by a single other subclass
C12J	Vinegar; its preparation
C13B	Production of sucrose; apparatus specially adapted therefor
C13K	Saccharides, other than sucrose, obtained from natural sources or by hydrolysis of naturally occurring di-, oligo-, or polysaccharides
	"Beverages" – manufacture of beverages (PCA 11)
A23L 2	Non-alcoholic beverages; dry compositions or concentrates therefor; their preparation
C12C	Brewing of beer
C12G	Wine; other alcoholic beverages; preparation thereof
C12H	Pasteurisation, sterilisation, preservation, purification, clarification or ageing of alcoholic beverages; methods for altering the alcohol content of fermented solutions or alcoholic beverages

End of Table 1

"Tobacco" – manufacture of tobacco products (PCA 12)	
A24	Tobacco; cigars; cigarettes; smokers' requisites
"Agrochemistry" – manufacture of pesticides and other agrochemical products (PCA 20.2)	
A01N	Preservations of bodies of humans or animals or plants or parts thereof; biocides, e.g., as disinfectants, as pesticides or as herbicides; pest repellents or attractants; plant growth regulators
A01P	Biocidal, pest repellent, pest attractant or plant growth regulatory activity of chemical compounds or preparations
"Machinery" – manufacture of agricultural and forestry machinery (PCA 28.3)	
A01B	Soil working in agriculture or forestry; parts, details, or accessories of agricultural machines or implements, in general
A01C	Planting; sowing; fertilising
A01D	Harvesting; moving
A01F	Threshing; baling of straw, hay or the like; stationary apparatus or hand tools for forming or binding straw, hay or the like into bundles; cutting of straw, hay or the like; storing agricultural or horticultural produce
A01G	Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or seaweed; forestry; watering
A01K	Animal husbandry; care of birds, fishes, insects; fishing; rearing or breeding animals, not otherwise provided for; new breeds of animals
A01M	Catching, trapping or scaring of animals; apparatus for the destruction of noxious animals or noxious plants
B27L	Removing bark or vestiges of branches; splitting wood; manufacture of veneer, wooden sticks, wood shavings, wood fibres or wood powder
"Packaging" (no direct equivalent in the PCA)	
B65B	Machines, apparatus or devices for, or methods of, packaging articles or materials; unpacking
B65C	Labelling or tagging machines, apparatus, or processes
B65D	Containers for storage or transport of articles or materials, e.g., bags, barrels, bottles, boxes, cans, cartons, crates, drums, jars, tanks, hoppers, forwarding containers; accessories, closures, or fitting therefor; packaging elements; packages

Note: Classes withdrawn from the current version of IPC, but present in the study of Klincewicz (2019), were not included.

In order to illustrate the macroeconomic activity the most common indicator (Drozdowicz-Bieć, 2012), that is Gross Domestic Product (GDP) was utilized, whereas because of missing data in series for manufacture of agricultural and forestry machinery and manufacture of agricultural and forestry machinery and no direct equivalent for the manufacture of packaging, the sectorial economic activity was represented by the sum of manufacture of food products, beverages and tobacco.

Because the PPO's standard practice is to work with annual filings, also the data on aggregated economic activity and economic activity in the agri-food sector extracted from the Eurostat database were annual. Of course, since recessions are identified when aggregated activity decreases for two quarters, it would be better to rely on data on a quarterly basis. From the other side though, business cycles often last longer than a year (Baxter & King, 1999;

Burns & Mitchell, 1946). It should be also highlighted that previous analyses of cyclicality in the Polish economy relies on periods of quite similar lengths of 17 (Skrzypczyńska, 2014) and 14 years (Gradzewicz et al., 2010).

Data on GDP in constant prices from 2015 (chain link volumes) were utilized, whereas as an index of real manufacture of food products, beverages and tobacco products serves an industrial production index, 2015 = 100 (IPI, called also industrial output index or industrial volume index). It is a business cycle indicator measuring changes in the price-adjusted output of an industry. We will call it agri-food sector output or just sectorial output. Both data sets were acquired from the Eurostat database (n.d.-a, n.d.-b).

Firstly, the three data series were presented. Particularly, the structure of patent filings in regard to technological areas and first applicants, and its changes in time were characterized. The further research was performed on logarithms and divided into two stages. In the morphological analysis the spectral density functions for time series were estimated and smoothed taking advantage of the Parzan window. The periodograms (that is estimators of the spectral density functions) show what portion of the variance of time series may be attributed to cycles of different frequencies (Skrzypczyński, 2010). The dominant frequencies of cyclical fluctuations were determined while filtering the data with the Christiano-Fitzgerald (2003) [CF] band-pass filter.

It is assumed that in the time series there are three kinds of fluctuations: a trend component connected with middle- and long-term fluctuations, a cycle component being a subject of our research, and short-term fluctuations of noise character. Spectral analysis relies on the representation of the time series in a frequency domain, whereas filtration strengthens fluctuations in cyclical frequencies, weakening or removing two other kinds of fluctuations. Specifically, the CF filter is an "ideal" filter approximation, which is optimal if the time series have unit root or are stationary around the deterministic trend. The aim of this stage was the general analysis of the extracted cycles in the economic activity and in the number of patent filings. It embraces the identification and comparison of turning point, lengths and variability of the cycles.

The aim of the second stage was to characterize the relationships between the cyclical components of variables. Three relationships were analyzed – patent filings vs. GDP, patent filings vs. sectorial output, and additionally GDP vs. sectorial output. Regarding patent activity, this stage consists of the analysis of cyclicality taking advantage of Pearson's linear correlation coefficients and dynamic correlations, as well as the analysis of leads and lags in relation to economic activity measures, where cross-correlations and phase shifts were utilized. Moreover, relative standard deviation and gains describe the amplitude of patent activity fluctuations in relation to the business cycle, while coherences say about the similarity of fluctuations. These methods enable measuring the strength of the correlation between variables, identifying the character of the relationship between variables (leading, simultaneous, lagging) and their relative variability.

It should be highlighted, that the analysis uses both statistics defined in the time domain (Pearson linear correlation coefficient, cross correlation, relative standard deviation) and the statistics defined in the frequency domain (cross correlation, phase shift, gain, coherence). The Pearson linear correlation coefficient indicates the strength of the coincident relationship, while cross-correlations allow to determine whether patent filings relative to the business cycle

are leading, coincident or lagging. 4 years of lags/leads of patent filings relative to business cycle indicators were taken into account, and it was assumed that maximum of the absolute value of the correlation coefficient for the n-th lag (lead) of patent filings to business cycle indicator suggests that patent filings are n-years lagged (ahead) relative to the business cycle indicator. Relative standard deviations were calculated through dividing standard deviation of patent filings by standard deviation of economic activity.

Measures of the cross-spectral analysis (dynamic correlation, phase shift, cross gain) enable the presentation of relationships between variables using frequency functions, what comes down to breaking the variables into components with different frequency bands (Gradzewicz et al., 2010). The analysis of relationships between patent filling and business cycle in different time horizons may be performed. Four measures were utilized. Dynamic correlations allow to determine, in which frequency bands the correlation relationships between variables are the strongest. Presentation of linear correlation coefficients as a function of frequency enables examining the strength and sign of the relation between variables for different periods of cyclical fluctuations. Phase shifts indicate which variables earlier and which later move into subsequent cycle phases. The nature of temporal connections (leading, coincident, lagging) is here presented as a function of frequency. Gains enable determining the relative amplitude of cyclical fluctuations of variables in certain frequency bands. Relative amplitude of fluctuations is treated as a function of frequency. Coherences measure the strength of the linear relationships in a regression of reference series on leads, lags and coincident values of the other variable for a given frequency (Skrzypczyńska, 2014).

The time series used to study relationships in the time domain were detrened with CF filter. As in Benhabib and Wen (2004) and Gradzewicz et al. (2010), fluctuations at business cycle frequencies ranging from to 2 to 10 years were extracted. The cycles obtained with the Hodrick-Prescott filter (1997) were very similar, albeit CF cycles regarding patent filings proved to be more smooth in time and therefore more appropriate for analysis of cycles.

The time series used to study relationships in the frequency domain weren't filtered before. The reason for that was that according to Benati (2001) using a filter before cross-spectral analyses may lead to disturbances. Omitting this step enables series periodograms remain without significant changes in the analyzed frequency bands. From these series the deterministic trends were subtracted. The KPSS stationarity test and the ADF root test indicated, that such series became stationary, so they could be treated with cross-spectral analysis tools.

Because of the patent data availability, the analyzed period was limited to 2006–2022. The spectral density analysis and extracting cyclical components regarding GDP and sectorial output were performed taking advantage of longer period of 24 years (2000–2023). Calculations were performed in Python, Excel and GRETL.

3. Results of the research

3.1. Changes in economic activity and the number of patent filings

According to the Eurostat data, the number of the Polish food system enterprises in 2020 in the analyzed technological areas were as follows: Food – 18162 (6.99% of the enterprises in the EU27), Beverages – 727 (2.35%), Machinery – 678 (1.13%), Agrochemistry – 55 (8.90%),

Tobacco – 25 (7.84%). The value of production (in mln euro) in 2020 amounted to: Food 53769 (6.41% of the EU production value in 2019), Beverages 7588.1 (5.28% of the EU production value in 2018), Tobacco 5944 (18.1%), Machinery 1698.5 (3.95%), Agrochemistry 183.8 in 2018 (1.84%). There is no class Packaging in the data on economic activity (Eurostat, n.d.-a).

The average number of patent filings in the period 2006–2022 was the highest in Food (85), Machinery (69) and Packaging (52), and lower in Agrochemistry (19), Tobacco (13) and Beverages (11). Comparing the number of enterprises, production value and number of patent fillings in 2020 (Figure 1), it appeared that 92% of enterprises dealing with Food is responsible for 78% of production value and theirs share in patent filings of the sector is about twice lower – 49%. 4% enterprises active in Beverages area is responsible for 11% of the agri-food sector's production value and only 3% of patent filings. The same with Tobacco – 25 enterprises (0% share) produce 9% value and make 5% patent filings. It could be said, that the old agri-food sector areas' share in the food system innovativeness could be higher. Far more inventive seem to be Agrochemistry and Machinery, which being responsible for 0 (55 enterprises) and 3% of all enterprises and 0 and 2% of production value, made in an example year 2020 32 and 11% of patent filings, respectively. These technological areas are therefore prospective and developing from the perspective of the whole food system.

Figure 2 illustrates numbers of patent filing in the Polish food system in the period 2006–2022, with division into technological areas. The number of patent filings in 2006 amounted to 144, whereas in 2002 it was 277, what means the increase by 92.4%. The highest increase was noticed in the areas of Beverages (216.7%), Food (135.9%), Tobacco (128.6%) and Machinery (147.4%), while the number of patents filings in Packaging decreases by 5.56% and in Agrochemistry increases in the lowest degree – by 22.2%.

The most striking is however the decrease in the number of patent filings generally from 2015, while in the period 2006–2015 a constant increase may be observed (with a slight decrease in 2008 due to the global financial crisis). The breakdown took place before the Covid-19 pandemic and before the war in Ukraine and therefore can't be explained by them. Only
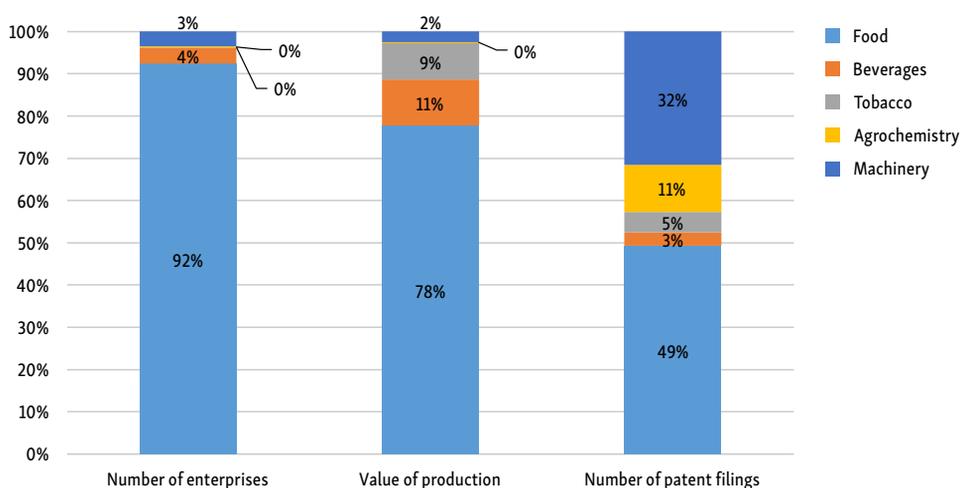

Figure 1. The structure and invention activity in the Polish food system in 2020
(source: own elaboration based on the PPO data)

deeper insight into the data gives the answer. The Packaging technological area is responsible for the decrease in the number of patents. Precisely, in the period 2018–2022 the decrease in the number of patents amounted to 62.2%. Almost 80% decline was in containers for storage or transport of articles or materials; accessories, closures, or fitting therefor; packaging elements; packages (B65D). The increase before 2018 and the drop after 2018 were connected with an intensive development of online sales, which induced the demand for various packaging maximizing the product protection.

Coefficients of variation in the number of patent filings in the period 2006–2022 were quite similar, ranging from 22% in Agrochemistry, 27% in Food, 30% in Machinery, to 36% in Packaging, 42% in Tobacco and 47% in Beverages.

Taking into account individual (sub-)sections, 677 out of 4227 were patent filings regarding containers for storage or transport of articles or materials; accessories, closures, or fitting therefor; packaging elements; packages (B65D). 510 patent filings concern preparation or processing of food and foodstuffs (A23L1) and more than 200 were noticed in the subsectors: A01N (Agrochemistry), A01K and A01G (Machinery) and A24 (Tobacco). It turned out that six out of 34 IPC (sub-)sections made up 53% of all patent filings.

In the analyzed period the most active in patenting were economic sector entities (54% of all patents) and higher education institutions (22%). Physical persons made 14% of patent filings, whereas research institutes 9%. The least active in patenting were the Polish Academy of Science entities (1%). Taking into account changes in time, from 2006 to 2022 the biggest increase in share was observed in patent activity of higher education institutions, which share increased from 11 to 44%, at the expanse of shares of physical persons and research institutes, which shares decreased from 24 to 7% and from 16 to 5%, respectively. The share of economic sector entities decreased from 48 to 44%.
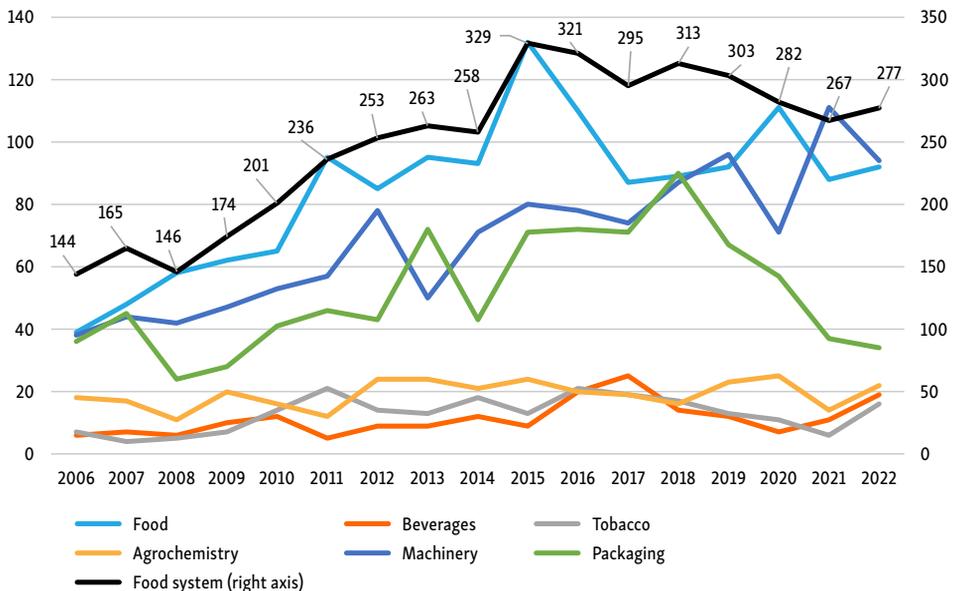

Figure 2. Patent filing in the Polish food system in the period 2006–2022
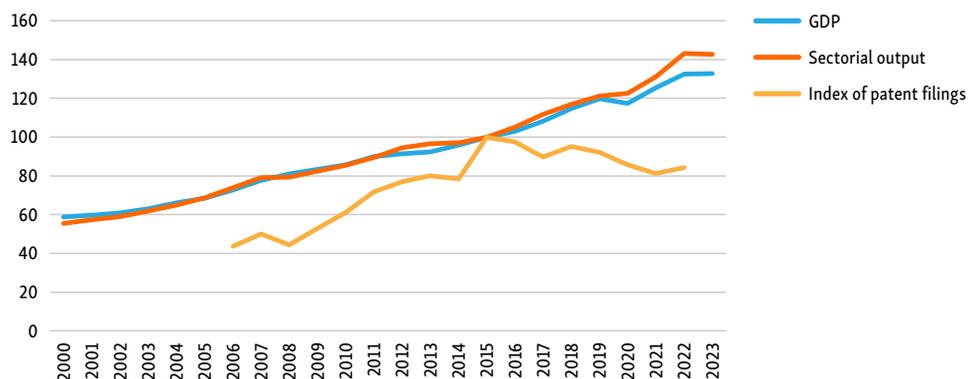(source: own elaboration based on the PPO data)

Figure 3. GDP, sectorial output and patent filings (indexes, 2015 = 100)
(source: own elaboration based on Eurostat and the Polish Patent Office data)

The index of patent filings, as well as indexes for GDP and output of the Polish agri-food sector, 2015 = 100 are presented in Figure 3. In the period 2006–2023 GDP in Poland increased by 82.8%, whereas sectorial output by 94.0%. Correlation coefficient value between GDP and patent index amounted to 0.81, between output and patent index – 0.80, and between sectorial and macroeconomic fluctuations – 1. These three-time series share the growing trend, but while it seems to be linear for business cycles, it will be rather quadratic for the patent filings.

3.2. The morphology of the cycles

Results of spectrum analysis (Figure 4) performed for the three analyzed series (logarithmized and stationary data) allow to indicate the dominant fluctuation frequencies, which determine the complex dynamics of cycles in macro- and sectorial variables. Variability of GDP is mostly shaped by cyclical fluctuations with a cycle length of ca. 3.5 years, what is in accordance with results received by Skrzypczyńska (2014). Longer cycles dominate in sectorial output – of 5–6 years, whereas in patent filings – cycles lasting 3.5–6 years. Longer cycles in the agri-food sector may be explained by the households tendency to smooth the food consumption path
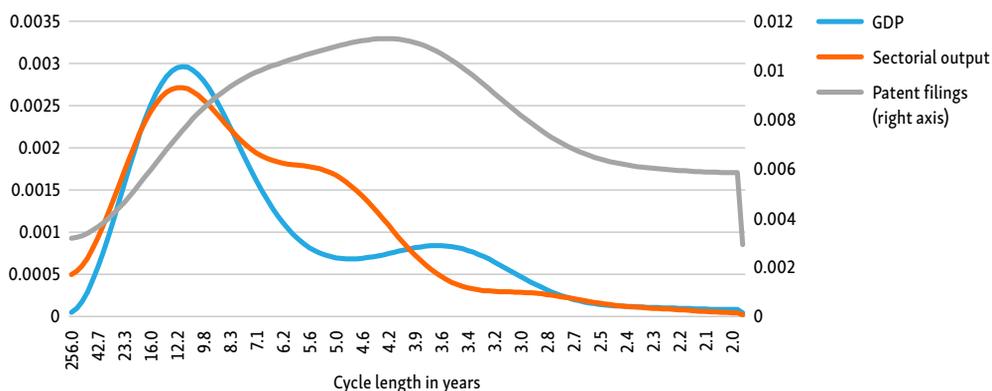

Figure 4. Spectral density functions of GDP, sectorial output and patent filings
(source: own calculations)

in time (Skrzypczyńska, 2014). Dominating cycles in patenting are longer than macroeconomic business cycle and shorter than sectorial business cycle, what may mean that entities decisions on patenting are quite sensitive. From the other side the role of fluctuations longer than 10 years, so in frequencies lower than that of a business cycle, is important only regarding GDP and sectorial output. Interestingly, in both series dominate fluctuations lasting 12 years. As the aim of the analysis is to characterise the relationship between patent and business cycles, fluctuations of length above 10 years were excluded.

Figure 5 presents cyclical fluctuations limited to those with a period of 2-10 years received with the CF filter. It may be interpreted that the Y axis presents the percentage deviations of the series from their long-term stochastic trends (Gradzewicz et al., 2010). Patents deviate maximally by 12% and minimally by 8%, sectorial output – by 3.7 and 3.2%, while GDP – by 2 and 3%, respectively. The variability of GDP is lower than those of two other cycles, what is in accordance with stylized facts about the economy (King & Rabelo, 1999; Stock & Watson, 1999). On average patents' troughs were higher than patents' peaks (–8.2 as compared to 6.5%), what indicates that the number of patent filings is more sensitive to negative phenomena in the economy. It was also more difficult to rise than to lower the macroeconomic and the sectorial business cycle – on average peaks means deviations of 1.3 and 2.3%, and troughs of –1.6 and –2.1%, respectively. Moreover, sectorial output cycles seem to be longer than GDP cycles and patent cycles. In the analyzed period in GDP and patent series four local minima and four local maxima were observed, whereas in sectorial output – only three minima and three maxima (Table 2). Patent cycles seem to be more in accordance with GDP cycles than with sectorial cycles. On the contrary, the agri-food sector seems to be not so vulnerable to aggregate fluctuation, as its decline and renewal phases last longer. Both results are quite surprising.

The cycles of GDP and sectorial output has one shared peak (in 2007) and two shared troughs (in 2010 and 2020), whereas the patent cycle seems to be more similar to the macroeconomic than to the sectorial business cycle. It shares with the GDP cycle three out of four peaks (in 2007, 2011, 2015), and GDP troughs proceed by a year three out of four patent troughs. The patent cycle has only one shared extrema with the sectorial output cycle (the 2007 peak), and two extrema are of the opposite sign (in 2015 and 2017).
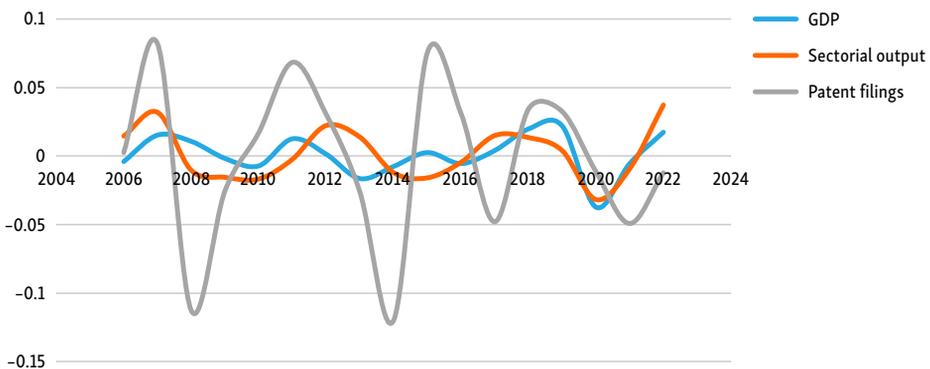

Figure 5. Fluctuations of cyclical components of real GDP, real sectorial output and the patent filings in the period 2006–2022 (in %) (source: own calculations)

The peaks in macroeconomic business cycle took place in 2007, 2011, 2015 and 2019, what is in accordance with the results obtained in the literature (Fic, 2009; Gradzewicz et al., 2010; Skrzypczyńska, 2014). The downswings following them were connected with effects of the world financial crisis in 2007, with the world economic downturn following it, and with the COVID-19 epidemic.

Table 2. Cycle phases and turning points of cyclical components of real GDP, real sectorial output and the patent filings in the period 2006–2022 (source: own calculations)

Variable	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
GDP	+	−	−	−	+	−	−	+	+	−	+	+	+	−	+	+
Sectorial output	+	−	−	−	+	+	−	−	−	+	+	−	−	−	+	+
Patent filings	+	−	+	+	+	−	−	−	+	−	−	+	−	−	−	+

Note: +/– means an increase/a decrease of cyclical component of the variable in regards to the previous year, darkened cells – local extrema.

3.3. The relationship between patent filings and economic activity

The values of linear correlation coefficients between cyclical components of the three analyzed variables (Table 3) indicate that changes in sectorial output are positively correlated with changes of GDP. The relationships between both business cycle and patent filings were positive, but insignificant. These results were confirmed by the values of correlation coefficients calculated for the given frequencies (Figure 6).

Agri-food sector output behaves procyclical in regards to GDP within the whole frequency domain. The positive relationship between patents and macroeconomic cycle is the strongest for cycles lasting 3.5–4 years, which are also the cycles dominating in GDP series in the analyzed period. For cycles longer than 6 years the relation started to be negative. Patent filings are positively correlated also with the agri-food sector output. The strongest correlation appears in shorter cycles of 2.5–3 years. In fact high level of correlations was obtained for all
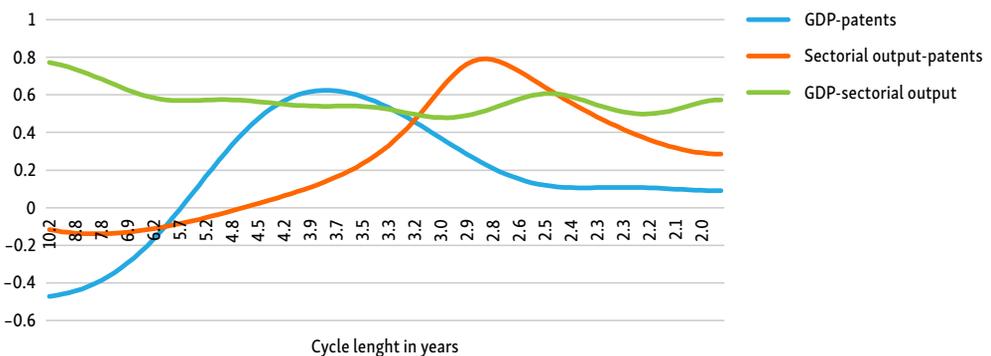

Figure 6. Dynamic correlations between GDP, sectorial output and patent filings (source: own calculations)

frequencies, what indicates that a mechanism of mutual relations between patent filings and business cycle is important for better understanding the behavior of both.

Table 3 presents correlations of leads and lags of patent filings with GDP and sectorial output as well as correlations of leads and lags of sectorial output with GDP. Sectorial output is procyclical, as well as its increase proceed the decrease in GDP by two years and these results are statistically significant. Patent filings appear to increase in four years after the sectorial output decline, and change simultaneously with the macroeconomic business cycle. However, both phenomena lack statistical significance.

Table 3. The linear correlation coefficients and cross-correlations between GDP, sectorial output and patent filings (source: own calculations)

Lead/Lag in years	Series leading in relation to business cycle				Series coincident	Series lagging in relation to business cycle			
	−4	−3	−2	−1	0	1	2	3	4
Patent filings in relation to GDP	0.246	−0.118	−0.213	0.122	*0.283*	−0.105	−0.158	0.082	−0.001
Patent filings in relation to sectorial output	0.144	0.047	−0.270	−0.250	−0.252	0.135	0.111	−0.059	*−0.311*
Sectorial output in relation to GDP	0.139	−0.023	−0.504	−0.065	*0.568*	0.110	−0.213	−0.258	0.070

Note: Dark cells mean coefficient statistically significant at the 1% level of significance, Italic values – maximum of absolute values.

Spectral indicators of phase shift between cyclical components of three variables (Figure 7) illustrate lags and leads of patents in reference to GDP and sectorial output, and lags and leads of sectorial output in reference to GDP for the given frequencies. The negative (positive) value means the lead (lag). It appeared that in all frequencies changes in patent filings proceed changes in agri-food sector, so they are a leading indicator of the sectorial economic activity. For dominating sectorial business cycles of 5–6 years the lead amounted to ca. 1.5 year. For shorter cycles it's becoming lower, e.g., for 4 years cycles, which dominate in patent filings series, the lead amounted to one year. This result highlights the importance of invention activity for the agri-food sector development in Poland, as well as the usefulness of cross-spectral analysis while looking for leading indicators of economic activity. The patent activity in the sector may be treated as the early warning indicator of sectorial economic activity (1–2 years before).

In relation to fluctuations in GDP patent filings seem to be lagging by one year for the cycles lasting ca. 2–5 years and leading by 1.5–2.5 years for longer cycles. Taking into account that the variability of GDP is mostly shaped by 3.5 year fluctuations, it may be concluded, although with some caution, that patent filings are lagging indicator of aggregated economic activity, what is in accordance with the economic theory saying that economic downturns influence the patent activity. Changes in sectorial output reveal the similar dual character – they are lagging for aggregate economic activity in higher frequencies (by one year in cycles shorter than 3.5 year) and leading (or even coincident) in lower frequencies. Taking into account the results of the analysis in the time domain, fluctuations of agri-food sector output should be regarded as coincident with GDP fluctuations.
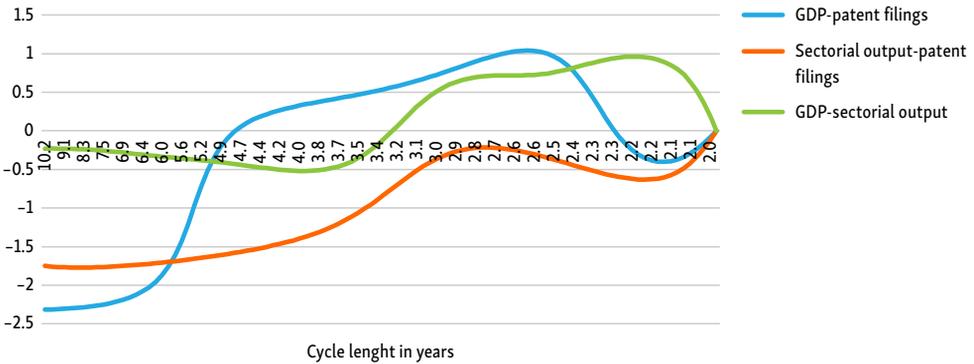
Figure 7. Phase shifts of patent filings relative to GDP and sectoral output, and of sectorial output relative to GDP (in years) (source: own calculations)

Table 4 illustrates the results of calculations of relative deviations for cyclical components of variables in relation to the macroeconomic and sectorial business cycles deviations (standard deviations ratio). The variability of patent filings is almost three times higher than the variability of GDP and ca. two times higher than variability of sectorial output. Sectorial output variability is one third higher than that of GDP. These results are just a quantification of our observations made while illustrating the cyclical fluctuation (see Figure 5).

Table 4. Standard deviation of the cyclical component (in %) (source: own calculations)

Variable	Standard cycle deviation	Standard deviation in relation to GDP standard deviation	Standard deviation in relation to sectorial output standard deviation
GDP	1.441	1	78
Sectorial output	1.843	128	1
Patent filings	5.677	394	308

Particularly, results of the gain analysis (Figure 8) indicate how this relative amplitude changes along different frequencies. Gain identifies in which frequencies the relative variability cumulates. Number 1 on the Y axis means that deviations of both variables analyzed are equal for a given frequency, values less than 1 mean that patent filings and sectorial output has higher amplitude compared to fluctuations of the reference series – GDP and sectorial output for a given frequency, and conversely if gain values exceed 1.

It appeared that all analyzed series fluctuate more than the reference series, what confirm the results obtained in the time domain. The amplitude in sectorial output is the most similar to that of GDP, especially for cycles lasting less than 3.5 years. The amplitudes of patent filings compared to business and sectorial cycles are very alike within the whole frequency domain with the exception of cycles of 5–6 years, where the patent fluctuations in reference to sectorial output are lower. The relative variability of patents cumulates in higher frequencies.

Additionally, in order to measure the strength of the linear relationships in a regression of reference series on leads, lags and coincident values of patent filings and sectorial output for a given frequency, we calculated the coherence (Figure 9). The results confirmed the previous
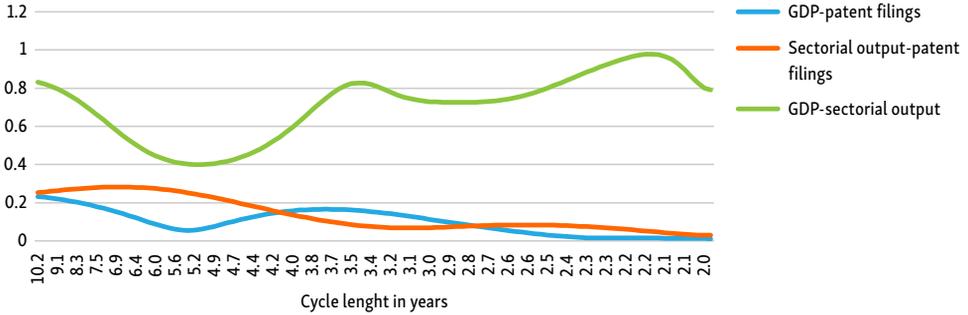
Figure 8. Gain of patent filings relative to GDP and sectoral output, and of sectorial output relative to GDP (source: own calculations)
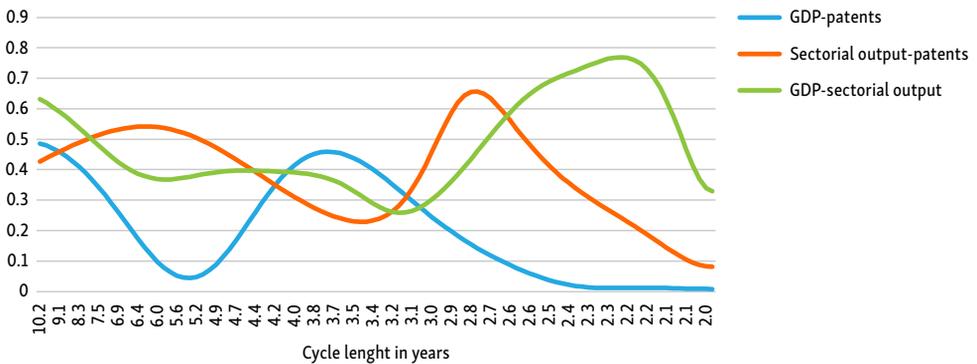

Figure 9. Coherence of patent filings relative to GDP and sectoral output, and of sectorial output relative to GDP (source: own calculations)

findings regarding similarity of macroeconomic and sectorial business cycles, especially in reference to higher frequencies. The cycles of patent filings are similar to sectorial business cycle in higher and lower frequencies (2.5–3-year and 6-year cycles), and to macroeconomic business cycle in regards to the 3.5-year cycles dominating in GDP. But in general patent filings seem to be more similar to the agri-food sector fluctuations.

4. Discussion

The purpose of the study was to investigate the sensitivity of patent filings in food system to the business cycle on the Polish economy example utilizing statistics defined in time and frequency domains. It was the first trial of looking on how firms from the food system innovate amid cyclical fluctuations.

The results obtained in the study enables answering the three research questions stated at the beginning of the paper. Patent activity in the Polish food system in the period 2006–2022 almost doubled. The half of patent filings was made in Food, one third in Machinery, while Agrochemistry took the third place. The highest growth in patent activity was observed in Beverages and Food and in these technological areas of the Polish food system the patent activity is about to be cumulated in future at the expense of Packaging and Agrochemistry,

which the best times have rather already behind them. The most active were economic sector entities and universities, which together made 76% of patent filings, 1/3 of which is owed to academics. This appears to be a good result. Poland seems to specialize in new containers for storage or transport of articles or materials, accessories, closures, or fitting therefor, packaging elements, packages, as well as in new ways of preparation or processing of food and foodstuffs.

Against the stated hypothesis, patent activity proved to be procyclical in regard to macroeconomic and sectorial business cycles, what is in accordance with the majority of empirical literature in the subject, both on the macroeconomic (e.g., European Commision, 2011; Guellec & Wunsch-Vincent, 2009; Hingley & Park, 2017; OECD, 2009; WIPO, 2010;), as well as microeconomic level (e.g., Geroski & Walters, 1995; Giedeman et al., 2006; Martinsson & Lf, 2009). This result means that the resource effect prevails over the opportunity cost effect. During upturns companies in the Polish food system gain broader access to internal resources, like cash flows or retained earnings, but also at the greater extend take advantage of external resources, like venture capital, subsidies and grants from public sector, which also become more accessible. In turn, during recessions prices of materials and labour in the food system seem not to fall. Consequently, possibilities of changing the allocation of resources and effort from production and marketing to innovations process become limited. In other words, during downturns both cost of conducting R&D and opportunity cost don't decrease in the sector. During recessions the sales loss resulting from redirecting resources to patent activity would be too high, so companies suspend doing this. Procyclicality of patent activity in the food system may result therefore from costs and structure of production factors.

The hypothesis of a leading character od patent activity against business cycle was confirmed only partially, as it turns out that patent filings leads the sectorial output, but are lagged in reference to GDP. The first result is important for stabilization policy, which aim is to alleviate the symptoms of slowdown in specific sectors. Patent activity in the food system may be treated as the early warning indicator of sectorial economic activity with a lead of one year. Moreover, it turns out that changes in the situation in the agri-food sector occur simultaneously for cycle lasting 2–3 years compared to changes in aggregated economic activity, what improves the effectiveness of the stabilization policy. Fiscal and monetary policy tools may be utilized in order to improve patent activity and therefore increase the economy performance. The second result is significant regarding forecasting patenting behavior, which is important for such areas as policy decision-making, strategic business planning and institutional operations.

Patent activity proved also to fluctuate much more in relation to the business cycle, and their cycles are more similar to the sectorial than macroeconomic business cycle. This may mean that there are other important factors shaping it, besides the business cycle.

At the end it must be added, that although not all patents are commercialized or of equal economic significance, they are continuously utilised as a proxy of successful and effective innovation activity being a source of economic development (e.g., Cheng et al., 2023; Wen et al., 2021). Intellectual property law has always been intended to stimulate the development of innovation and ensure order for all parties of this process. Moreover, in the era of AI, the patenting system doesn't give the field, as in 2023 there were approximately 122 thousands AI patents granted (HAI, 2025).

It should be also highlighted that the majority of results were obtained thanks to the cross-spectral analysis. Taking into account the character of the relationship between variables across different lengths of cycles proved to be very valuable and should be recommended. Also analyzing the whole food system shouldn't be feared of, although its borders haven't been finally defined yet. Assuring food security, nutrition and poverty reduction, not compromising the economic, social and environmental bases for food security and nutrition of future generations (FAO, 2018), that is transition to the sustainable food system, becomes an obvious aim of the policy and the quantitative analyses and databases should try to follow this perspective and adjust.

5. Conclusions

The article starts with the sentence, that invention activity is an important innovation development factor, as it not only imposes changes in economic activity, but also often leads to the completely new structures within the sector. We showed that patent activity anticipate changes in sectorial output and it's lagging in reference to aggregated economic activity, which changes are in fact coincidence with changes in sectorial output.

The main finding for the policy is that patents may serve as a leading indicator for the food system, what can be used in several ways. As drops and rises in patent filings precede ups and downs in sectorial business cycle, it's beneficial to start to use patent data strategically in order to accelerate economic growth and slow down the system downturns. Firstly, patents trends reveal where innovation is accelerating, and government may design research funding, extension services and educational programs around these areas. Secondly, thanks to global patent mapping of innovation hotspots and technology gaps across regions and value chains, R&D incentives may be directed where domestic capacity is low compared to global one. Thirdly, identifying which technologies attract private investment and where returns may be high enables creating clusters around them, decreasing the risk of many valuable investments. Moreover, emerging patent domains signal future labour market demand, what enables earlier human capital and skills building. Patent offices can enhance innovation data use e.g., by providing patent dashboards, innovation trends identification or facilitating knowledge transfer. Parallelly it should be checked if innovation supports sustainability goals, not just productivity, whereas international comparisons should encourage trade and technology strategic partnerships.

In order to look deeper and to understand what is the true relationship between patenting and the food system in the broad economy context, also the character of inventions should be reveled, and their potential to carry out a creative destruction of the present structures.

From the other side, in order to perform a more detailed analysis of the impact of patent filings on the Polish economy, for example by taking advantage of the increasingly popular in the field VAR modelling with Granger causality tests, we would need longer or more frequent data series. By utilising international data on patenting, a panel regression analysis may be performed, which enables studying if innovation changes are attributable to business cycles or to other economic conditions. Moreover, including comparative perspective with other countries could enable answering how national and EU policies on innovation and intellectual

property influence patenting trends. The survey exploring how specific companies behave in relation to the business cycle, would also give another dimension. For example, exploring differences between large corporations and SMEs could provide a more detailed view of patent activity drivers.

Author contributions

J. K.-G. and J. G. conceived the study and were responsible for the design and development of the data analysis, for data collection, analysis and interpretation.

Disclosure statement

Authors don't have any competing financial, professional, or personal interests from other parties.

References

Acosta, M., Coronado, D., & Romero, C. (2015). Linking public support, R&D, innovation and productivity: New evidence from the Spanish food industry. *Food Policy*, *57*, 50–61. https://doi.org/10.1016/j.foodpol.2015.09.005

Aghion, P., & Saint-Paul, G. (1998). Virtues of bad times interaction between productivity growth and economic fluctuations. *Macroeconomic Dynamics*, *2*(3), 322–344. https://doi.org/10.1017/S1365100598008025

Aghion, P., Askenazy P., Berman N., Cette G., & Eymard, L. (2012). Credit constraints and the cyclicality of R&D investment: Evidence from France. *Journal of the European Economic Association*, *10*(5), 1001–1024. https://doi.org/10.1111/j.1542-4774.2012.01093.x

Albors-Garrigós, J., Monzo, J. M., & Garcia-Segovia, P. (2018). Knowledge dynamics as drivers of innovation in Haute Cuisine and culinary services. *Industry and Innovation*, *25*(1), 84–111. https://doi.org/10.1080/13662716.2016.1268950

Allred, B. B., & Park, W. G. (2007). The influence of patent protection on firm innovation investment in manufacturing industries. *Journal of International Management*, *13*(2), 91–109. https://doi.org/10.1016/j.intman.2007.02.001

Amantae, T. K., Song, W., & Wang, J. (2024). Intellectual property rights in the agri-food chains: A systematic review and bibliometric analysis. *World Patent Information*, *77*, Article 102279. https://doi.org/10.1016/j.wpi.2024.102279

Avermaete, T., Viaene, J., Morgan, E. J., Pitts, E., Crawford, N., & Mahon, D. (2004). Determinants of product and process innovation in small food manufacturing firms. *Trends in Food Science & Technology*, *15*(10), 474–483. https://doi.org/10.1016/j.tifs.2004.04.005

Baczko, T., Puchała-Krzywina, E., & Pieńkowska, M. (2008). Innowacyjność przemysłu spożywczego – wyniki badań [Innovativeness of the food industry – research results]. In M. Adamowicz (Ed.), *Innowacje i innowacyjność w sektorze agrobiznesu* [Innovations and innovativeness in the agribusiness sector] (vol. 1., pp. 105–116). SGGW Publishing House.

Baczko, T. (2018). Przedsiębiorstwa patentujące i ich znaczenie w tworzeniu struktur wiedzy w Polsce [Patenting companies and their importance in creating knowledge structures in Poland]. In A., Adamczak (Ed.), *100 lat ochrony własności przemysłowej w Polsce. Księga jubileuszowa Urzędu Patentowego Rzeczypospolitej Polskiej* [100 years of industrial property protection in Poland. Jubilee book of the Patent Office of the Republic of Poland] (pp. 1613–1627). Wolters Kluwer.

Barragán-Ocaña, A., Olvera-Treviño, M., de los Á., & Silva-Borjas, P. (2023). Technological innovation for sustainable development: Is agricultural and food nanotechnology a viable alternative? *World Patent Information*, *75*(2), Article 102235. https://doi.org/10.1016/j.wpi.2023.102235

Baxter, M., & King, R. (1999). Measuring business cycles: Approximate band-pass filters for economic time series. *Review of Economics and Statistics*, *81*(4), 575–593. https://doi.org/10.1162/003465399558454

Beaudry, P., & Portier, F. (2014). News-driven business cycles: Insights and challenges. *Journal of Economic Literature*, *52*(4), 993–1074. https://doi.org/10.1257/jel.52.4.993

Benati, L. (2001). *Band-pass filtering, cointegration, and business cycle analysis*. (Bank of England Working Paper No. 142) Bank of England. https://doi.org/10.2139/ssrn.293180

Benhabib, J., & Wen, Y. (2004). Indeterminacy, aggregate demand, and the real business cycle. *Journal of Monetary Economics*, *51*(3), 503–530. https://doi.org/10.1016/j.jmoneco.2003.08.011

Bigliardi, B., & Galati, F. (2013). Innovation trends in the food industry: The case of functional foods. *Trends in Food Science & Technology*, *31*(2), 118–129. https://doi.org/10.1016/j.tifs.2013.03.006

Bryceson, K., & Yaseen, A. (2018). Smart technologies: Disruptive technologies and the agrifood industry – fit for practice? In O. Bak (Ed.), *E-Business and supply chain integration*: *Strategies and case studies from industry* (pp. 27–50). Kogan Page.

Burns, A., & Mitchell, W. (1946). *Measuring business cycles* (NBER Working Paper). NBER.

Caballero, R. J., & Hammour, M. L. (1994). The cleansing effect of recessions. *American Economic Review*, *84*(5), 1350–1368.

Calafat-Marzal, C., Sánchez-García, M., Martí, L., & Puertas, R. (2023). Agri-food 4.0: Drivers and links to innovation and eco-innovation. *Computers and Electronics in Agriculture*, *207*, Article 107700. https://doi.org/10.1016/j.compag.2023.107700

Carlton, D., & Perloff, J. (2005). *Modern industrial organization*. Pearson.

Chaparro-Banegas, N., Sánchez-Garcia, M., Calafat, C., & Roig-Tierno, N. (2024). Transforming the agri-food sector through eco-innovation: A path to sustainability and technological progress. *Business Strategy and the Environment*, *33*(8), 9075–9097. https://doi.org/10.1002/bse.3968

Cheng, K., Chen, H., Zhang, F., & Zhang, M. (2023). China's high-quality innovation development from an institutional perspective: Regional differences and convergence. *Technological and Economic Development of Economy*, *29*(6), 1657–1686. https://doi.org/10.3846/tede.2023.20214

Christiano, L. J., & Fitzgerald, T. J. (2003). The band pass filter. *International Economic Review*, *44*(2), 435–465. https://doi.org/10.1111/1468-2354.t01-1-00076

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2000). *Protecting their intellectual assets*: *Appropriability conditions and why US manufacturing firms patent (or not)* (NBER Working Paper No. 7552). National Bureau of Economic Research. https://doi.org/10.3386/w7552

Cooper, R., & Haltiwanger, J. (1993). The aggregate implications of machine replacement: Theory and evidence. *The American Economic Review*, *83*(3), 360–382.

Danguy, J., de Rassenfosse, G., & van Pottelsberghe de la Potterie, B. (2014). On the origins of the worldwide surge in patenting: An industry perspective on the R&D-patent relationship. *Industrial and Corporate Change*, *23*(2), 535–572. https://doi.org/10.1093/icc/dtt042

De Rassenfosse, G., & van Pottelsberghe de la Potterie, B. (2007). Per un pugno di dollari: a first look at the price elasticity of patents. *Oxford Review of Economic Policy*, *23*(4), 558–604. https://doi.org/10.1093/oxrep/grm032

De Rassenfosse, G., & van Pottelsberghe de la Potterie, B. (2012). On the price elasticity of demand for patents. *Oxford Bulletin of Economics and Statistics*, *74*(1), 58–77. https://doi.org/j.1468-0084.2011.00638.x

Drozdowicz-Bieć, M. (2012). *Cykle i wskaźniki koniunktury* [Business cycles and indicators]. Poltext.

Dubois, P., Griffith, R., & O'Connell, M. (2018). The effects of banning advertising in junk food markets. *The Review of Economic Studies*, *85*, 396–436. https://doi.org/10.1093/restud/rdx025

European Commission. (2011). *Innovation union competitiveness report*. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/87066

Eurostat (n.d.-a). *Gross Domestic Product* (*GDP*) *and main components* (*output, expenditure and income*). Retrieved September 28, 2024, from https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_GDP/default/table?lang=en

Eurostat (n.d.-b). *Production in industry – annual data*. Retrieved September 28, 2024, from https://ec.europa.eu/eurostat/databrowser/view/STS_INPR_A/default/table?lang=en

Fairbairn, M., Kish, Z., & Guthman, J. (2022). Pitching agri-food tech: performativity and non-disruptive disruption in Silicon Valley. *Journal of Cultural Economy*, *15*(5), 652–670. https://doi.org/10.1080/17530350.2022.2085142

Food and agriculture Organization. (2018). *Sustainable food systems – concept and framework*. https://openknowledge.fao.org/server/api/core/bitstreams/b620989c-407b-4caf-a152-f790f55fec71/content

Fic, T. (2009). Cykl koniunkturalny w Polsce. Wnioski z modeli Markowa [Business cycle in the economy of Poland. Observations derived from Markov chains]. *Ekonomista*, *1*, 49–66.

Figiel, S., Gospodarowicz, M., Grochowska, R., Kuberska, D., Kufel-Gajda, J., Oliński, M., & Wasilewski, A. (2017). *Innovation performance of thwe Polish agri-food sector*: *Key determinants and prospects for improvements*. Institute of Agricultural and Food Economics – National Research Institute.

Geroski, P., & Walters, C. (1995). Innovative activity over the business cycle. *Economic Journal*, *105*(431), 916–928. https://doi.org/10.2307/2235158

Giedeman, D., Isley, P., & Simons, G. (2006). Innovation and the business cycle: A comparison of the U.S. semiconductor and automobile industries. *International Advances in Economics Research*, *12*(2), 277–286. https://doi.org/10.1007/s11294-006-9009-3

Gradzewicz, M., Growiec, J., Hagemejer, J., & Popowski, P. (2010). Cykl koniunkturalny w Polsce – wnioski z analizy spektralnej [The business cycle in Poland – conclusions from spectral analysis]. *Bank i Kredyt*, *41*(5), 41–76.

Griffith, R., O'Connell, M., & Smith, K. (2017). The importance of product reformulation versus consumer choice in improving diet quality. *Economica*, *84*, 34–53. https://doi.org/10.1111/ecca.12192

Griliches, Z. (1984). Patent statistics as economic indicators: A survey. In Z. Griliches (Ed.), *R&D and productivity*: *The econometric evidence* (pp. 287–343). University of Chicago Press.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, *28*(4), 1661–1707. https://www.jstor.org/stable/2727442

Guellec, D., & Wunsch-Vincent, S. (2009). *Policy responses to the economic crisis*: *Investing in innovation for long-term growth*. (OECD Digital Economy Papers No. 159). OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2009/06/policy-responses-to-the-economic-crisis_g17a1d14/222138024482.pdf

HAI. (2025). *The Artifical Inteligence Index Report 2025*. Institute for Human-Centered AI, Stanford University. https://hai.stanford.edu/assets/files/hai_ai_index_report_2025.pdf

Hall, B. (2005). Exploring the patent explosion. *Journal of Technology Transfer*, *30*, 35–48. https://doi.org/10.1007/s10961-004-4356-9

Hall, R. E. (1991). Labor demand, labor supply, and employement volatility. *NBER Macroeconomics Annual*, *6*, 17–47. https://doi.org/10.1086/654155

Harrington, R. J. (2004). Part I: The culinary innovation process, a barrier to imitation. *Journal of Foodservice Business Research*, *7*(3), 35–57. https://doi.org/10.1300/J369v07n03_04

Heger, D. (2004). *The link between firms' innovation decision and the business cycle*: *An empirical analysis* (Centre for European Economic Research Discussion Paper No. 04-085). ZEW. https://doi.org/10.2139/ssrn.686712

Hingley, P., & Park, W. (2017). Do business cycles affect patenting? Evidence from European Patent Office filings. *Technological Forecasting and Social Change*, *116*, 76–86. https://doi.org/10.1016/j.techfore.2016.11.003

Hodrick, R. J., & Prescott, E. C. (1997). Postwar U.S. business cycles: An empirical investigation. *Journal of Money, Credit and Banking*, *29*(1), 1–16. https://doi.org/10.2307/2953682

Howell, S., Lerner, J., Nanda, R., & Townsend, R. (2023). *How resilient is venture-backed innovation? Evidence from four decades of U.S. patenting* (NBER Working Paper No. 27150). National Bureau of Economic Research. https://www.nber.org/system/files/working_papers/w27150/w27150.pdf

Hu, A., & Jefferson, G. (2009). A great wall of patents: What is behind Chinas recent patent explosion. *Journal of Development Economics*, *90*(1), 57–68. https://doi.org/10.1016/j.jdeveco.2008.11.004

Jones, C. I., & Williams, J. C. (1998). Measuring the social return to R&D. *The Quarterly Journal of Economics, President and Fellows of Harvard College*, *113*(4), 119–1135. https://doi.org/10.1162/003355398555856

King, R., & Rabelo, S. (1999). Resuscitating real business cycles. In J. Taylor & M. Woodford (Eds.), *Handbook of macroeconomics* (pp. 927–1007). Elsevier. https://doi.org/10.1016/S1574-0048(99)10022-3

Klincewicz, K. (2019). Aktywność patentowa w sektorze rolno-spożywczym a inteligentne specjalizacje województw [Patent activity in the agri-food sector and smart specialisations of Polish regions]. *Polskie Problemy Zarządzania – Management Issues*, *16*(79), 37–82. https://doi.org/10.7172/1644-9584.79.2

Kortum, S., & Lerner, J. (1999). What is behind the recent surge in patenting? *Research Policy*, *28*, 1–22. https://doi.org/10.1016/S0048-7333(98)00082-1

Liu, L.-j., Cao, C., & Song, M. (2014). Chinas agricultural patents: How has their value changed amid recent patent boom? *Technological Forecasting and Social Change*, *88*, 106–121. https://doi.org/10.1016/j.techfore.2014.06.018

Lopez-Garcia, P., Montero, J. M., & Moral-Benito, E. (2012). *Business cycles and investment in intangibles: Evidence from Spanish firms* (Banco de Espana Working Paper No. 1219). Banco de Espana. https://doi.org/10.2139/ssrn.2064535

Lybbert, T. J., & Zolas, N. J. (2014). Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity. *Research Policy*, *43*, 530–542. https://doi.org/10.1016/j.respol.2013.09.001

Mansfield, E. (1998). Academic research and industrial innovation: An update of empirical findings. *Research Policy*, *26*(7–8), 773–776. https://doi.org/10.1016/S0048-7333(97)00043-7

Martinsson, G., & Lf, H. (2009). *Impact of economic crises on innovation activity: Firm level evidence from patent data* (Centre of Excellence for Science and Innovation Studies Working Paper No. 200). CESIS. https://static.sys.kth.se/itm/wp/cesis/cesiswp200.pdf

Meade, N., & Islam, T. (2006). Modelling and forecasting the diffusion of innovation – A 25-year Review. *International Journal of Forecasting*, *22*(3), 519–545. https://doi.org/10.1016/j.ijforecast.2006.01.005

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food manufacturing waste: A review. *Journal of Cleaner Production*, *65*, 28–41. https://doi.org/10.1016/j.jclepro.2013.10.051

Miranda-Agrippino, S., Hacioğlu-Hoke, S., & Bluwstein, K. (2024). *Patents, news, and business cycles* (Bank of England Working Paper No. 788). Bank of England.

Mylan, J., Geels, F. W., Gee, S., McMeekin, A., & Foster, C. (2015). Eco-innovation and retailers in milk, beef and bread chains: Enriching environmental supply chain management with insights from innovation studies. *Journal of Cleaner Production*, *107*, 20–30. https://doi.org/10.1016/j.jclepro.2014.09.065

National Statistical Office. (2023). *Działalność innowacyjna przedsiębiorstw w latach 2020–2022* [Innovation activities of enterprises in the years 2020–2022]. Główny Urząd Statystyczny. https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/nauka-i-technika/dzialalnosc-innowacyjna-przedsiebiorstw-w-latach-2020-2022,2,22.html

Organisation for Economic Co-operation and Development. (2009). Patent intensity over the business cycle. In *OECD science, technology and industry scoreboard 2009*. (p. 37). OECD Publishing. https://www.oecd.org/content/dam/oecd/en/publications/reports/2009/12/oecd-science-technology-and-industry-scoreboard-2009_g1ghb819/sti_scoreboard-2009-en.pdf

Organisation for Economic Co-operation and Development. (2021). *Making better policies for food systems*. OECD Publishing. https://doi.org/10.1787/ddfba4de-en

Okoń-Horodyńska, E., Sierotowicz, T., & Wisła, R. (2012). *Measuring patent activity of economic branches with the use of concordance tables*. Patent Office of the Republic of Poland.

Othmani, A., Yedder, B. N., & Sayef, B. (2023). *The cointegration relationship between patent, domestic investment and economic growth in United States of America* (Munich Personal RePEc Archive Paper No. 118245). MPRA.

Ottenbacher, M., & Harrington, R. J. (2007). The culinary innovation process. *Journal of Culinary Science & Techn*ology, *5*(4), 9–35. https://doi.org/10.1300/J385v05n04_02

Park, W. (1999). Impact of the international patent system on productivity and technology diffusion. In O. Lippert (Ed.), *Competitive strategies for the protection of intellectual property* (pp. 47–72). Fraser Institute.

Ponta, L., Puliga, G., Manzini, R., & Cincotti, S. (2022). Sustainability-oriented innovation and co-patenting role in agri-food sector: Empirical analysis with patents. *Technological Forecasting and Social Change*, *178*, Article 121595. https://doi.org/10.1016/j.techfore.2022.121595

Rafferty, M., & Funk, M. (2008). Asymmetric effects of the business cycle on firm-financed R&D. *Economics of Innovation and New Technology*, *17*(5), 497–510. https://doi.org/10.1080/10438590701407232

Santeramo, F. G., Carlucci, D., De Devitiis, B., Seccia, A., Stasi, A., Viscecchia, R. I., & Nardone, G. (2018). Emerging trends in European food, diets and food industry. *Food Research International*, *104*, 39–47. https://doi.org/10.1016/j.foodres.2017.10.039

Sanyal, P., & Jaffe, A. (2005). Peanut butter patents versus the New Economy: Does the increased rate of patenting signal more invention or just lower standards? *Annales d'Economie et de Statistique*, *79/80*, 211–240. https://doi.org/10.2307/20777576

Scherer, F. M. (1983). The propensity to patent. *International Journal of Industrial Organization*, *1*, 107–128. https://doi.org/10.1016/0167-7187(83)90026-7

Schmoch, U. (2008). *Concept of a technology classification for country comparisons: Final report to the World Intellectual Property Organisation*. Fraunhofer Institute for Systems and Innovation Research. https://www.wipo.int/documents/2948119/3215563/wipo_ipc_technology.pdf

Schumpeter, J. A. (1939). *Business cycles: A theoretical, historical, and statistical analysis of the capitalist process*. McGraw-Hill.

Science Advice for Policy by European Academies. (2020). *A sustainable food system for the European Union*. SAPEA. https://hal.inrae.fr/hal-02934171/file/sustainable-food-system-report%20final.pdf

Skrzypczyńska, M. (2014). Cyclical processes in the Polish economy. *Central European Journal of Economic Modelling and Econometrics*, *6*(3), 153–192.

Skrzypczyński, P. (2010). *Metody spektralne w analizie cyklu koniunkturalnego gospodarki Polskej* [Spectral methods in the analysis of the business cycle of the Polish economy] (Materiały i Studia Narodowego Banku Polskiego No. 252). NBP. https://static.nbp.pl/publikacje/materialy-i-studia/ms252.pdf

Standing Committee on Agricultural Research. (2021). *Narrative. European partnership on safe and sustainable food systems for people, planet and climate*. SCAR. https://scar-europe.org/images/FOOD/Main_actions/Food-Systems-Partnership_Narrative-06-2021.pdf

Standing Committee on Agricultural Research. (2023). *Sustainable food systems partnerships for people, planet and climate. Strategic research and innovation agenda* (*SRIA*). SCAR. https://scar-europe.org/images/FOOD/Main_actions/SFS_Partnership_SRIA_31012023.pdf

Stock, J. H., Watson, M. W. (1999). Business cycle fluctuations in US macroeconomic times series. In J. B. Taylor & M. Woodford (Eds.), *Handbook of macroeconomics* (pp. 3–64). Elsevier. https://doi.org/10.1016/S1574-0048(99)01004-6

Suchoń, A. (2010). Własność przemysłowa w sektorze rolno-spożywczym; wybrane zagadnienia prawne [Industrial property in the Agri-food sector, selected legal issues]. *Zeszyty Naukowe SGGW w Warszawie – Problemy Rolnictwa Światowego*, *10*(4), 101–15. https://doi.org/10.22630/PRS.2010.10.4.52

Thumm, N. (2001). Management of intellectual property rights in European biotechnology firms. *Technological Forecasting and Social Change*, *67*(2–3), 259–272. https://doi.org/10.1016/S0040-1625(00)00099-8

Trott, P., & Simms, C. (2017). An examination of product innovation in low- and medium-technology industries: Cases from the UK packaged food sector. *Research Policy*, *46*(3), 605–623. https://doi.org/10.1016/j.respol.2017.01.007

United Nations. (2022). *Sustainable development goals report 2022*. https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf

Van Looy, B., Vereyen, C., & Schmoch, U. (2014). *Patent statistics*: *Concordance IPC V8 – NACE Rev.2*. Eurostat.

Wen, J., Deng, P., Zhang, Q., & Chang, C.-P. (2021). Is higher government efficiency bringing about higher innovation? *Technological and Economic Development of Economy*, *27*(3), 626–655. https://doi.org/10.3846/tede.2021.14269

Wisła, R. (2018). Statystyka patentowa w badaniach ekonomicznych [Patent statistics in economic research]. In A. Adamczak (Ed.), *100 lat ochrony własności przemysłowej w Polsce. Księga jubileuszowa Urzędu Patentowego Rzeczypospolitej Polskiej* [100 years of industrial property protection in Poland. Jubilee book of the Patent Office of the Republic of Poland] (pp. 1613–1627). Wolters Kluwer.

World Intellectual Property Organization. (2010). Special theme: The impact of the economic crisis and recovery on innovation. In *World intellectual property indicators* (pp. 14–31). WIPO. https://www.wipo.int/edocs/pubdocs/en/intproperty/941/wipo_pub_941_2010.pdf