THE AMPLIFICATION OF THE BULLWHIP EFFECT IN THE ELECTRONICS INDUSTRY UNDER THE INFLUENCE OF PANIC BUYING

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Abstract

Purpose: The primary purpose of this article is to show the causes and consequences of supply shortages in semiconductors for the automotive and electronics industries in 2021. The subsidiary objectives describe the behaviour of company managers that contributed to this and make proposals for strengthening the resilience of supply chains to demand impulses through their digitization and transparency of information and material flows.

The stated objectives are due to the research gap in the impact of panic buying on the bullwhip effect in the supply chains.

Method: The study was based on secondary and primary sources. An analysis of secondary data in the form of reports of Polish listed companies producing electronic devices for the years 2019 and 2021 was carried out in terms of inventory turnover. The year 2019 is treated as a base year, *i.e.*, before the Covid-19 pandemic. In contrast, 2021 presents a period when electronic device manufacturers were already experiencing significant delays in semiconductor deliveries. For primary sources, one semiconductor manufacturer and three electronic device manufacturers were interviewed.

Findings: The increase in demand for electronic components, extended delivery times and reduced availability has caused electronic device manufacturers to increase their purchases and inventories for fear of production stoppages, further screwing up the demand spiral and component shortages. Decisions to increase inventories were to some extent based on the practice of panic buying and demonstrated a lack of transparency in supply chains.

Implications: The author proposes implementing digitalization and transparency in the supply network in place of the practice based on panic buying, which would significantly reduce production downtime for car makers and electronic device manufacturers, as well as the negative financial consequences related to production stoppages and scrapping of obsolete inventory.

Keywords: bullwhip effect, panic buying, semiconductor shortage, supply chain disruptions, Covid-19

Paper type: Research paper

1. Introduction

The research problem undertaken by the author deals with the issue of the behaviour of purchasing managers of electronic manufacturers in the context of the extension of delivery times for electronic components and the consequences of their decisions. Comparing the years 2019 and 2021, delivery times for integrated circuits (IC) have lengthened from several weeks to about one year (Scott, 2021). 2019 was a year of relative stability, even before the supply-demand disruptions caused by the Covid-19 pandemic. In contrast, 2021 presents a period in which electronics manufacturers were already experiencing significant delays in semiconductor supply, resulting in production problems and even supply chain outages. The production hold-up in the automotive industry (Pelle and Tabajdi, 2021; Ramani *et al.*, 2022), which has perhaps the greatest bargaining power, demonstrates the worldwide nature of the phenomenon. In Europe, the automotive industry accounts for 37% of semiconductor demand. It is estimated that an hour-long stoppage of an automotive production line costs about 600,000 EUR, and a week-long shutdown is as much as 100 million EUR (Evertiq, 2021).

Due to a shortage of semiconductors, auto manufacturers were forced to shut down production and reduce output. In 2021, they could lose 210 billion USD in revenue, and the number of unproduced cars could reach 7.7 million pieces. The main reason for the semiconductor shortage was the ordering strategy of the automakers, who did not have stock, and when the pandemic broke out, decided to cancel orders (Evertiq, 2021). In addition, the share of semiconductor value in the car is on an upward trend, generating increased demand. In 2021, the average value of semiconductors was 450 USD, and for 2026 it is estimated to be 700 USD, due to technological developments in the C.A.S.E. (Connectivity, ADAS, Sharing, Electrification) segment (Evertiq, 2021). Semiconductor shortages also affected global manufacturers of consumer products. For instance, Panasonic decided to abandon TV production in the Czech Republic (tek.info.pl, 2021), and Apple was to reduce the production of the iPhone 13 by 10 million units in 2021 (Evertiq, 2021). Semiconductor shortages have affected virtually every industry, though to varying degrees, because there are thousands of types of different integrated circuits on the market dedicated to different electronic devices with varying demand. Experts estimate that the global IC shortage cost the U.S. economy 240 billion USD in 2021 (CBS News, 2022). Accordingly, the following specific research questions were formulated:

1. What were the reasons for the increased delivery times for electronic components?
2. How did electronics manufacturers respond to the increase in delivery times for electronic components? What further impact did this have on the availability of electronic components?
3. What are the past adverse bullwhip effects, and what is expected?

4. What measures could have been taken to reduce the negative effects of limited availability of electronic components?

Therefore, this article's main purpose is to show the causes of supply shortages in semiconductors for the automotive and electronics industries in 2021. The subsidiary objectives are as follows: to reveal the behaviour of company managers that contributed to this and the consequences of their decisions; to make proposals for strengthening the resilience of supply chains to demand impulses through digitization and transparency of information and material flows.

The following hypotheses were formulated:

H1. Shortages in the market for electronic components in 2021 resulted not only from increased demand for finished electronic devices but also from the building of anticipatory inventories by electronic device manufacturers.

H2. The increase in inventories at electronic device manufacturers during the shortage of electronic components in 2021 was due to the practice based on panic buying.

The author points out that the extended semiconductor supply times of up to a year and the limited availability of semiconductors are not due to a reduction of semiconductor production, but are the result of a bullwhip effect and a phenomenon that should be called panic buying. The post-lock downturn recovery due to Covid-19 of 2020 first led, through the mechanism of production system dynamics in the semiconductor industry, to a maximum loading of production resources and thus an exponential increase in delivery times over a very short period of time, and then to a panic among electronic device manufacturers, who began to buy and order components from the market in excess quantities, and even for those products that were not in the current production plan or were in distant forecasts. As a result, a certain amount of semiconductor manufacturers' capacity was addressed to build excess inventory at electronic device manufacturers instead of servicing current demand. This not only led to production stoppages, but paradoxically to a record increase in the value of inventories of electronic device manufacturers, which resulted on the one hand from having excess quantities of components unnecessary for current production, and on the other from the increase in prices due to the excess of demand over supply. While the demand for semiconductors will remain high in the coming years due to the development of electromobility and the Internet of Things, the increase in semiconductor production stimulated by very high profitability will gradually lead to improved availability and shorter delivery times. As a consequence, manufacturers of electronic devices will move away from a policy of stockpiling based largely on the practice of panic buying in favour of ordering supplies to meet current customer orders. At the same time, a serious financial problem will be the consequences of incurring the costs of financing excessive inventories and, what is much more painful, the need to scrap

them or, at best, sell them for a fraction of their value. Another negative bullwhip effect may be the overproduction of ICs upstream in the supply chain, leading to intense competition and reduced profits or losses in the semiconductor industry.

2. Literature review

2.1. The bullwhip effect in semiconductor supply chains

Referring to the first hypothesis, which says about building anticipatory inventories along with the extension of the delivery time due to the increase in final demand, the bullwhip effect, also known as the Forrester effect, should be analysed. It is widely described in the literature by Lee *et al*. (1997a, 1997b), Metters (1997), Chen *et al*. (2000) or Dejonckheere *et al*. (2003). It consists in increasing the amplitude of demand changes up the supply chain, which causes shortages in the first place, and after an excessive increase in supply, it generates overproduction and excessive inventories. However, there are very few references to this phenomenon in the semiconductor industry.

Meanwhile, the crisis related to shortages of integrated circuits is the most severe worldwide in the post-Covid-19 period. Mohammad *et al*. (2022) point to three causes of chip shortages, namely Covid-19 disruptions, semiconductor supply chain (SSC) complexity and geopolitical issues. Covid-19 disruptions were said to involve demand, supply and workforce disruptions. Demand disruptions consisted of increased demand for working from home (WFH) products such as laptops and tablets and decreased demand for consumer electronics. Automakers cut production and their suppliers reduced their chip orders. Supply disruptions involved a global halt in production, including semiconductors, as well as reductions in air travel and airport operations in 2020. Workforce disruptions, in turn, meant a massive shift to WFH in the short term, triggering demand for remote work equipment. On the one hand, the mandatory quarantine badly affected employee morale, while on the other hand, companies managed to maintain the continuity of their operations. Another reason for the shortages was said to be SSC complexity, *i.e.,* the highly complex production of integrated circuits, which requires hundreds of technological processes and movement across many factories around the world. This, with demand increasing beyond manufacturing capacity, very quickly led to inefficiencies in the entire manufacturing system and extended delivery times by many months. The last of the reasons cited are geopolitical issues, related to trade restrictions between Japan and South Korea (chemical components for semiconductor production), or the trade war between the US and China, which has led, among other things, to export restrictions on China's largest IC manufacturer – Semiconductor Manufacturing International Corporation (SMIC).

Mohammad *et al*. (2022), however, encourage the search for areas where improvements can lead to the most significant increase in SSC resilience. The considerations undertaken in this article respond to some extent to the indicated research gap. To the indicated causes of shortages, one would have to add increased purchases by electronics manufacturers, triggered by the fear of production stoppage, as will be demonstrated in the empirical part of this article. Moreover, it would be appropriate to develop the theme of SSC complexity in the context of the manufacturing capacity of the semiconductor industry. Due to the enormous capital intensity of this industry, entrepreneurs seek to maximize their manufacturing capacity. Monch *et al.* (2018) indicate that the cost of setting up a semiconductor factory is up to nearly 10 billion USD. However, press reports, indicate that the investment could be much higher, such as Samsung's factory, which is to be built in the state of Texas for 17 billion USD and begin operations in 2024 (Evertiq, 2022). In view of the above, even a small increase in demand with the maximum factory load policy in place, must lead to a significant increase in the queue for customer orders. As Suri points out (2010, pp. 71-83), with a very high load on the means of production, especially above 90%, even a slight increase in demand results in an exponential increase in the waiting time, as is evident from the queuing theory.

Analysing the bullwhip effect in the semiconductor industry, 2021 appears to have been a year of shortages, which caused a number of negative consequences downstream the supply chain by necessitating a reduction in the production of finished goods. On the other hand, in the upper part of the supply chain, it had a positive impact on the margins and profits of IC manufacturers, as well as distributors. On the one hand, chipmakers realizing record profits and believing that consumer demand will continue to grow have made decisions to launch huge investments in increasing manufacturing capacity. On the other hand, however, national governments seeing huge problems on the production side of finished chip-equipped products, as well as seeking geopolitical independence, have made decisions to subsidize investments in research and new chip factories. The US has done this through the 52.7 billion USD Chips and Science Act (The White House, 2022), South Korea by K-semiconductor strategy to support 451 billion USD investment (Jaewon, 2021), European Union, through the European Chips Act, has decided to invest 43 billion EUR (European Chips Act, 2022), China under the 'Made in China 2025' program through successive tranches of tax relief, *e.g.,* worth 204 billion RMB in 2021 (Au, 2021). It can therefore be expected that record investments in new chip factories, which will be launched in a few years, will lead to overcapacity and the release of excessive inventories. In this way, the demand wave will be replaced by the supply wave, causing another negative bullwhip effect but this time in the upstream part of the supply chain.

2.2. Bibliometric analysis of 'panic buying'

The concept of panic buying contained in the second hypothesis requires a bibliometric analysis. Figure 1 presents a bibliometric analysis which shows 5 clusters.

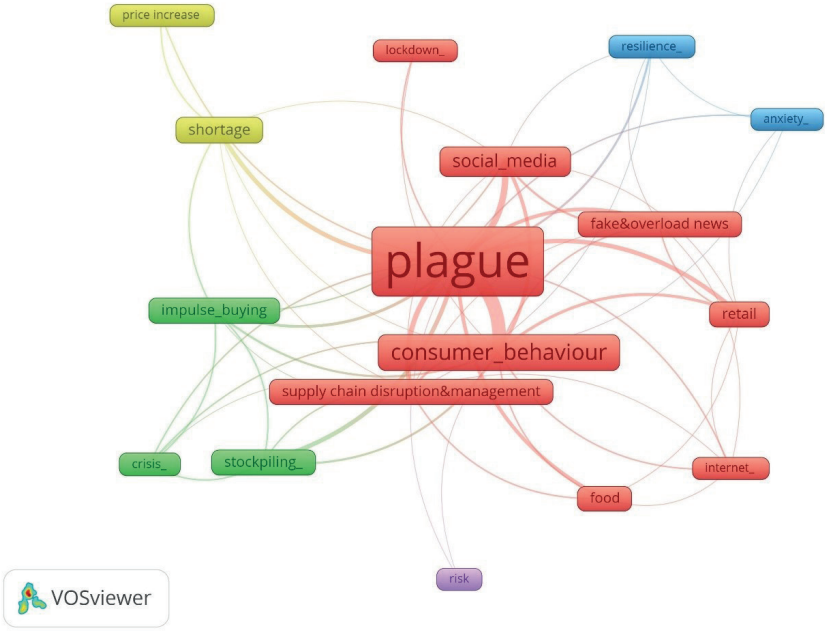

Figure 1.
Bibliometric analysis of 'panic buying'

Source: Own study using VOSviewer_1.6.19 software.

Referring to the keyword panic buying, at the centre is Covid 19, which, within one cluster, is combined with lockdowns and interruptions in supply chains, which, because of media coverage and intimidation of people, must have triggered consumer behaviour on the retail side of intense – panic buying of food. Another cluster is anxiety and resilience. Anxiety is linked to consumer behaviour and retailing. In turn, resilience refers not only to the pandemic itself, but also to the issue of supply chains and media messages, which turned out to be exaggerated and falsified to fuel the spiral of fear. However, the smallest cluster, *i.e.*, risk, connects pandemic and consumer behaviour. Referring to the last two clusters, it can be seen that the pandemic and panic buying in the area of supply chain management caused crisis and shortages, which on the one hand impulsively intensified purchases and influenced stockpiling. On the other hand, it triggered price increases. An analysis of the abstracts of scientific articles published indicates that the economic phenomena described relate to consumer behaviour or problems on the retail side, related to shortages and price increases of

mainly basic products needed for life, such as food, medical, or hygiene products. Ovezmyradov (2022) points to the negative consequences of consumer panic buying in terms of causing the bullwhip effect. The cause of panic buying is the 'irrational or speculative belief of consumers about lower availability and higher price in the future'. However, in the context of the current research, the focus is not on consumer behaviour induced by panic buying, but on the behaviour of supply chain actors in the electronics industry. The bibliometric analysis indicates that while the impact of panic buying among consumers has been recognized, there is absolutely no analysis of the phenomenon among supply chain managers, who, after all, as humans, are subject to similar concerns, though in the context of securing the continuity of their businesses, not households. Therefore, one can point to a research gap in the area of studying panic buying among supply chain managers and the impact on their decisions, as well as the effects of those decisions.

3. Research method

The study was based on secondary and primary sources.

An analysis of secondary data in the form of reports of Polish listed companies producing electronic devices (OEM – Original Equipment Manufacturer) for the years 2019 and 2021 was carried out in terms of total inventory turnover (materials, semi-finished and work-in-progress, finished goods, commodities) and materials alone with changes in operating income and profits. This allowed verification of H1. In addition, four selected companies were interviewed for H2 verification.

With regard to the analysis of secondary data, the research sample was based on a report of 100 Polish manufacturers of electronic devices in Poland (Jaeszke, 2022). Out of 100 companies, 15 were listed on the Warsaw Stock Exchange and were selected for the study. Three of them, *i.e.*, Medicalgorithm, Zortrax and Vigo Photonics, were excluded from the study. The first two due to conducting more commercial than production activities (lack of stocks of materials for production), and the third due to the production of components (EPI-wafers, infrared detectors, infrared detection modules) rather than electronic devices. In turn, in relation to three companies, *i.e.,* Apator, Lena Lighting, and Relpol, their individual reports were used for the analysis, not consolidated, so as not to include other business ventures. The analysis covered revenues, operating profit, total inventories (materials, semi-finished products and work in progress, finished products, goods) and inventories of materials for the production of finished products, the values of which were obtained from published and publicly available stock exchange reports for 2019 and 2021. The year 2019 is treated as a base year, *i.e.*, before the Covid-19 pandemic and the extension of the delivery time for electronic components. In turn, 2021 presents a period when manufacturers of electronic devices and car

makers have already experienced significant delays in semiconductor deliveries, which resulted in production problems and even downtime. Based on the collected data, material and total inventory cycles in days were counted, which take into account the dynamics of revenues in the compared periods. This allows for an objective comparison of changes that have taken place in the area of inventory value development. In addition, the amounts of revenues, operating profit, total and material inventories in absolute terms were summarized, which allowed assessing the dynamics of the changes taking place. The source data and the results of the indicator calculations are presented in Table 1.

The bibliometric analysis of panic buying was based on the Scopus database, filtering keywords that excluded subject areas outside Business, Management and Accounting/ Social Sciences/ Economics, Econometrics & Finance/ Decision Sciences, and included document types: article (88), conference paper (6), review (3). The total number of filtered documents was 97: 2 by 2000, 10 by 2018, and 85 by 2022. So, the concept of panic buying appeared in publications basically with the Covid-19 pandemic. The bibliometric analysis was visualized using the VOSviewer program. Out of 430 keywords, including 2 occurrences, 61 words were obtained. Then, thanks to the developed thesaurus (data are presented in the annex in Table 2), cleaning search results were carried out, as a result of which, out of the remaining 385 words and taking into account 2 occurrences, 17 keywords remained. The visualization was based on the fractionalization method (Van Eck and Waltman, 2009). The bibliometric analysis is presented in Figure 1.

Concerning the primary sources, interviews were conducted with one manufacturer of integrated circuits and three manufacturers of electronic devices. The chipmaker has been chosen non-randomly. Interviews among electronics manufacturers were limited to three; they were selected from Table 1, applying the following criteria: 1. the material inventory cycle in days increased between 2019 and 2021; 2. they agreed to be interviewed. The selection was non-random. The interviews made it possible to answer the research questions and achieve the subsidiary objective related to the behaviour of company managers.

4. Results

4.1. The impact of shortages of electronic components on the inventories of electronic device manufacturers

Increased delivery times for electronic components triggered by increased demand for electronic devices should result in a reduction in material inventories of electronic device manufacturers, as well as a reduction in total inventories, which also include semi-finished products, work in progress, goods and finished goods. Meanwhile, analysis of secondary data of the surveyed companies for 2019

		2019		31.12.2019				2021		31.12.2021						
No.	Company	Net Sales	Operating profit	Material stock	Inventory pro days	Total stock	Inventory pro days	Net Sales	Operating profit	Material stock	Inventory pro days		Change	Total stock	Inventory pro days		Change
1	Apator SA	262 967 000	12 210 000	18 221 000	**25**	34 734 000	48	282 486 000	-10 364 000	67 654 000	**87**	↑	**246%**	91 811 000	119	↑	146%
2	ACAutogaz SA	222 682 000	46 283 000	19 038 000	**31**	50 778 000	83	206 296 000	29 771 000	32 394 000	**57**	↑	**84%**	70 263 000	124	↑	49%
3	LUG SA	168 501 000	-5 678 000	25 729 000	**56**	41 550 000	90	203 919 000	4 350 000	41 133 000	**74**	↑	**32%**	64 532 000	116	↑	28%
4	APS Energia SA	134 758 000	13 036 000	4 817 000	**13**	12 486 000	34	113 257 000	10 973 000	12 016 000	**39**	↑	**197%**	21 965 000	71	↑	109%
5	Elzab SA	124 251 000	9 024 000	16 807 000	**49**	32 227 000	95	161 203 000	16 930 000	15 163 000	**34**	↓	**-30%**	34 396 000	78	↓	-18%
6	Aplisens SA	118 512 000	17 398 000	13 112 000	**40**	36 865 000	114	121 404 000	21 613 000	17 778 000	**53**	↑	**32%**	43 191 000	130	↑	14%
7	Lena Lighting SA	118 387 000	8 016 000	17 169 000	**53**	22 529 000	69	145 875 000	10 986 000	32 536 000	**81**	↑	**54%**	39 671 000	99	↑	43%
8	Relpol SA	110 683 000	6 378 000	10 236 000	**34**	31 827 000	105	128 601 000	7 946 000	15 377 000	**44**	↑	**29%**	38 906 000	110	↑	5%
9	Sonel SA	109 040 000	10 796 000	10 127 000	**34**	28 558 000	96	158 135 000	15 811 000	20 110 000	**46**	↑	**37%**	47 266 000	109	↑	14%
10	ML System SA	93 378 000	5 116 000	8 007 000	**31**	9 615 000	38	188 805 000	4 412 000	32 128 000	**62**	↑	**98%**	57 706 000	112	↑	197%
11	Creotech Instruments SA	25 486 000	329 000	1 227 129	**18**	1 811 129	26	33 356 000	985 000	3 451 376	**38**	↑	**115%**	4 616 079	51	↑	95%
12	CM INTERNATIONAL SA	18 185 459	1 868 609	1 220 777	**25**	2 858 859	57	22 565 092	1 852 786	1 066 457	**17**	↓	**-30%**	4 346 134	70	↑	23%
	Razem	1 506 830 459	124 776 609	145 710 906	**35**	305 838 988	74	1 765 902 092	115 265 786	290 806 833	**60**	↑	**70%**	518 669 213	107	↑	45%

Sales, profit and stock in PLN.

Table 1. Stocks of selected electronic device manufacturers for the years 2019 and 2021

Source: Own study based on financial reports of companies listed on the Warsaw Stock Exchange.

(the base year before the Covid 19 pandemic) and 2021 (the year of increased demand and component shortages) shows the opposite trend (Table 1).

Material inventories doubled in value, while total inventories increased by 70%. The increase in total inventories was mainly dictated by the increase in the value of material inventories. Since there was an increase in revenue, in order to objectively summarize inventory changes, it was necessary to compare material and total inventory cycles in days. They increased by 70 and 45%, respectively. Figure 2 shows the material inventory cycle in days for 2019 and 2021.

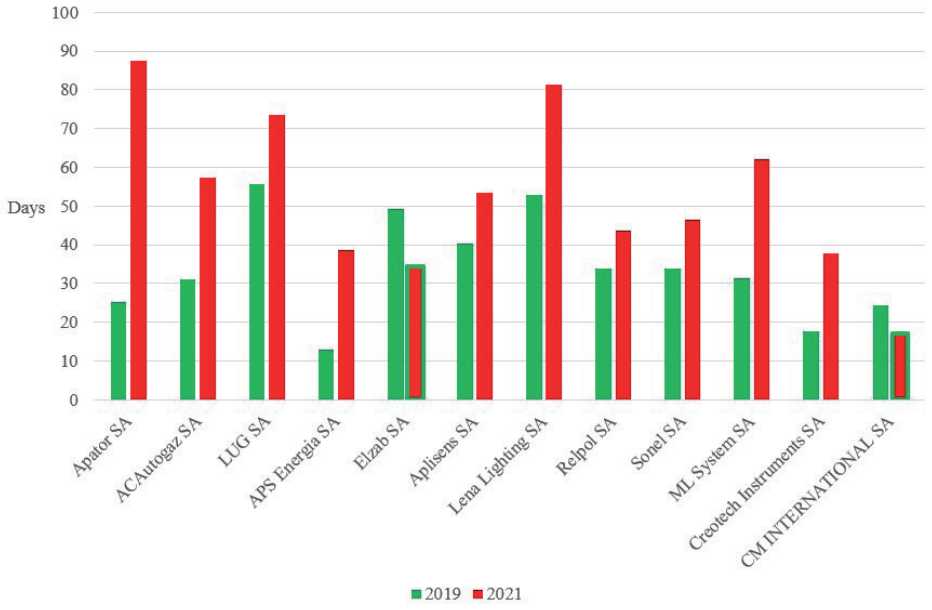

Figure 2. Material inventory cycles in days of selected electronic device manufacturers for the years 2019 and 2021

Source: Own study based on financial reports of companies listed on the Warsaw Stock Exchange.

The comparison of inventory cycles in days is also important due to the fact that the shortages of electronic components have certainly triggered an increase in their prices, as pointed out in the financial statements of the listed companies surveyed. An increase in the price of electronic components, and therefore an increase in production costs at the surveyed companies, would have to be offset, at least in part, by an increase in the price of finished goods. However, it is unclear to what extent the increase in revenue is due to the increase in the price of finished goods, and to what extent it is due to a change in the number of products delivered to the market. The reported 17% increase in revenues with a decrease in operating profit of only 8% and profitability from 8.3% to 6.5% effectively rules out the option of an increase in material prices of as much as 70% (extending the material inventory cycle in days). Theoretically, this would be possible if, in the base year, *i.e.*, 2019, the share of material costs in revenue represented a very low share

(up to about 25%), and the number of products sold in 2021 would remain at the same level or even decrease. However, using the statistical data of the most similar group of industrial enterprises by PKWiU in Poland, *i.e.,* those producing computers, electronic and optical products, it can be noted that the consumption of materials and energy in the structure of costs by type amounted to 78.4% in 2019 (Outlays and results in industry in 2019, 2020) and 82.2% in 2021 (Outlays and results in industry in 2021, 2022). In addition: 1a. net sales revenue at current prices in 2020 (relative to 2019) increased by 5.5%; 1b. net profit on sales in 2020 (relative to 2019) increased by 10.1%; 1c. prices of output sold increased by 0.1% during 2020; 2a. net sales revenue at current prices in 2021 (relative to 2020) increased by 30.3%; 2b. Net profit on sales in 2021 (relative to 2020) increased by 31.7%; 2c. prices of output sold increased by 4% during 2021 (Statistical Bulletin No 9/2022, 2022). The statistics presented show an upward trend in revenues and an increased growth rate in net profit, which clearly indicates that if the increase in material costs were to be 70% (the extension of the material inventory cycle in days), then in 2020-21 the increase in the share of material and energy consumption in the structure of generic costs would have to increase by much more than 3.8% (82.2%-78.4%), and the prices of finished goods would have to increase by much more than 4.1% (0.1%+4%).

Thus, it should be considered that during the period of electronic component shortages, inventories not only increased in value, which can only be justified to some extent by the increase in the purchase price of materials, but above all increased in number. This means that companies built up anticipatory inventories fearing their depletion, which, in addition to increased final demand, must have triggered even greater demand and even greater shortages of electronic components in the market. Thus, the bullwhip effect appeared, increasing the amplitude of demand upstream in the supply chain, which, once demand stabilizes and supply increases, will eventually lead to the emergence of excess inventory. Based on the analysis of secondary data conducted, there are no grounds to reject the first hypothesis. Therefore, it can be concluded that shortages in the electronic components market in 2021 resulted not only from increased demand for finished electronic devices, but also from the building of anticipatory inventories by electronic device manufacturers.

The behaviour of manufacturers of electronic devices, which led to an increase in material stocks, on the one hand, proves that they were thrifty and rationally striving to meet future demand. On the other hand, it points to the lack of transparency in the supply chain with regard to final demand, inventory, and production capacity, which, in the context of already available ICT technologies, constitutes an untapped economic potential and generates excessive costs, ultimately leading to a waste of resources. The bullwhip effect caused by managerial decisions amplifies the insufficiency of supply in relation to increased

final demand. This results in longer delivery times and even more, causes a fight for the availability of components and an increase in prices, which is naturally accepted by manufacturers of electronic devices. Due to very long delivery times in 2021, exceeding even one year, purchasing decisions regarding the assortment and quantities are made on the basis of forecasts with a very large error. Figure 3 shows the exponential dependence of the forecast error on the planned horizon. Therefore, it can be expected that the forecast error with a 50-week planning horizon will be many times greater than the planning error with a 20-week horizon, which was still in operation in 2019 at the time of balanced demand and supply of semiconductors.

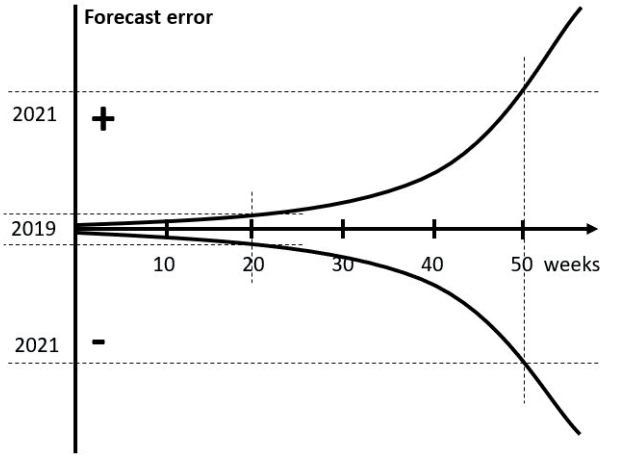

Figure 3. Forecast error and planning horizons for semiconductors

Source: Own study based on (Christopher, 2011, p. 84).

Due to ordering quantities and assortments for which there is no reported demand yet and based on a very long forecast horizon, the implemented purchasing practice inevitably leads to negative consequences. On the one hand, to incurring the cost of financing excessive inventories that would be useful to other electronics manufacturers at the time, and, on the other hand, to the necessity of reselling them at a fraction of the purchase price due to the lack of emergence of expected demand or scrapping them after their expiration date. While the first negative effect of increased financing costs had to be revealed already in 2021, the second effect related to the loss of value of stored semiconductors will only become apparent in the following years. With a long planning horizon, there is a high probability of a change not only in the volume of demand, but above all in the ordered range of finished products, which in turn may mean the need to use components other than those stored. Furthermore, the shelf life of semiconductors should not exceed two years due to oxidation of the pins and deterioration of the

quality of electrical connections. However, the managers' priority is to ensure the continuity of production, and the negative consequences, especially those postponed in time, recede into the background. Managers seem to treat them like insurance policy costs.

4.2. Reasons for the increase in material inventories at manufacturers of electronic devices

Since the effects of the implemented purchasing practice by companies in the form of building up anticipatory inventories to ensure continuity of production are known, it is still necessary to analyse the stimulants of the decisions made. Hence, one IC manufacturer and three electronic device manufacturers were interviewed from among those indicated in Table 1. The main questions were the following: 1. Have electronic device manufacturers experienced increased semiconductor delivery times in 2021? To what extent? 2. If so, has this caused delays in the production of finished products? To what extent? 3. How have companies tried to protect themselves from the negative effects of extended semiconductor delivery times? 4. If companies experienced extended delivery times and component shortages, what was the reason for the increase in material inventories at the end of 2021? 5. Were the purchasing decisions made based on sales forecasts and derived strictly from calculated needs in MRP (Material Requirements Planning) modules based on finished goods BOMs (Bills of Materials), or were they calculated manually and largely based on purchases of available quantities in isolation from the demand visible in the ERP (Enterprise Resource Planning) system? 6. Were purchasing decisions based on hard price negotiations or zero-one acceptance of the price offered? 7. Were purchases in 2021 made in an atmosphere of panic caused by component unavailability?

The results from the interviews are presented in the following four case study sections:

1) The chipmaker points to four reasons for the increase in material inventories at electronics manufacturers: 1. increased prices of integrated circuits; 2. shortages in the supply of ordered BOMs, leading to a situation in which the lack of even one component precluded the production of finished goods and the consumption of already accumulated inventories; 3. unstable and excessive demand, end customers looking for the availability of products placed orders with many manufacturers of electronic devices, finally closing the transaction only with the supplier with the shortest order fulfilment time; 4. buying materials in a panic, due to the fear of lack of availability or further extension of delivery time.
2) The manufacturer of electronic devices produced individually and in short series (usually several to several dozen pieces) pointed to three main reasons for the increased stocks in 2021: 1. a strategic customer delayed the

date of receipt of products, which meant that material stocks were not used for production; 2. increased purchases of components were made for fear of limiting their availability; 3. higher purchase prices incurred due to increased market demand. Orders were placed in accordance with the needs generated from the system and additionally in the event of information from suppliers about prolonged delivery times and an increased risk of unavailability. Occasionally, components were purchased from Asian brokers through qualified distributors of electronic components. In crisis situations, the purchasing department received very strong support from the development department, which in the event of unavailability of components proposed replacements and redesigned devices. There was no panic in purchasing practice, continuity of production was maintained, and emerging problems were resolved on an ongoing basis. The respondent pointed out that this is not the first time that delivery times have been extended, but never before has the crisis been so deep. Each purchase decision was preceded by market research by sending at least three inquiries.

3) In turn, the manufacturer of electronic devices in quantities exceeding one hundred thousand products per month indicated five reasons for excessive stocks: 1. very large forecast errors with the waiting time for component deliveries from 1 to 1.5 years, which, given the diverse range of finished products, has a particularly significant impact; 2. errors in bills of materials and production plans resulting from the ignorance of employees; 3. failure to reduce redundant orders from suppliers due to the risk of falling out of the queue at its end; 4. increase in prices of electronic components; 5. Excessive stockpiling due to suppliers' attitude to keep stock on-site. The respondent pointed to taking the following countermeasures: 1. selection of alternative components; 2. placing orders for components very well in advance – up to 1.5 years; 3. purchases from brokers at higher prices (up to ten times); 4. borrowing or resale of components. Thanks to the countermeasures taken, there was no complete stoppage of production, as was the case in the automotive industry. However, there were weekly delays. Due to the lack of credibility of the production plan in the ERP system, the needs were recalculated manually using spreadsheets. Thus, orders were placed manually, in isolation from the material needs generated by the system. With regard to price negotiations, the respondent indicates that the increases were imposed on a zero-one basis. Failure to accept the higher price meant a cancellation of orders and refusal of future deliveries by suppliers. It was similar in the case of collecting offers that were accepted or not. The priority, however, was the build-up of inventories, which took place somewhat in an atmosphere of panic caused by the fear of stopping production, which the respondent agreed to call soft.

4) The last interview was conducted with a manufacturer of electronic devices also produced on a large scale. The respondent indicated that delivery times for electronic components, which in 2019 ranged from 10 to 35 weeks, increased to 50 weeks, and some integrated circuits entered the allocation, which means that the manufacturer did not confirm the delivery date. The only certainty was that the delivery time would be longer than 50 weeks and could be, for example, 100 or 150 weeks. The limited availability of components and extended delivery times significantly disturbed the normal functioning of the company, but the safety measures taken prevented the plant from stopping production. There were only shifts of several days of previously planned production orders due to waiting for the missing component. At that time, the production of other products was launched much earlier. As part of the security measures, the company: 1. accumulated stocks, buying available components from the market to secure production for a year ahead; 2. diversified suppliers by making decisions to purchase components at higher prices from other distributors; sporadically, in order to maintain production continuity and under the condition of maintaining the profitability of the manufactured product, components worth less than one dollar were purchased from brokers at prices five or even ten times higher; 3. replacements that were available on the market were qualified, to which engineers devoted 80% of their time, thus significantly reducing the work on new projects; 4. orders were placed a year in advance. At the same time, as indicated by the respondent, the company was not afraid of building up stocks in the context of changes in demand, because the specificity of the manufactured products guaranteed the use of the collected components, the only unknown was the date of their consumption. As a consequence of the activities carried out, the number of stored electronic components increased significantly, which, additionally, taking into account the average increase in prices by approximately 10%, resulted in a significant increase in the value of inventories. Due to a certain feature of the ERP system, which can only show the needs for the indicated component in the BOM, and not for the replacement currently available on the market, the needs were calculated manually using a spreadsheet. Thus, orders were issued in the ERP system by hand. In turn, in relation to negotiations, the efforts made brought little results due to much weaker bargaining power. The company was primarily interested in building inventories so that production would not stop. The respondent admitted that there was a bit of panic in their purchasing decisions.

It should also be noted that manufacturers of electronic devices use not only electronic components for the production of their products, but also plastics,

metals, and their derivatives such as housings, electrical wires, electrical connectors, and fasteners. Hence, the share of electronic components in the case of the last of the surveyed companies is in the range of 30-40% of the value of purchased materials. This means that the extension of the material inventory cycle from 35 to 60 days, *i.e*., by 70% (Table 1), must result from a much greater extension of the electronic components inventory cycle. However, it is impossible to estimate this impact without having numerical data, especially since delivery times for other material groups have also been extended and material prices have increased.

Based on interviews with representatives of four companies, it should be considered that there are grounds for rejecting the second hypothesis:

H2: The increase in inventories at electronic device manufacturers during the shortage of electronic components in 2021 was due to the practice based on panic buying.

The reasons for rejecting the hypothesis are the indications of the respondents, saying that there were also other reasons for building increased inventories, including significant changes in demand in the long planning horizon, an increase in component prices, and the fear of an even greater reduction in the availability of electronic components. Thus, based on the interviews, the following thesis can be formulated:

One of the reasons for the increase in inventories at electronic device manufacturers during the shortage of electronic components in 2021 was the practice based on panic buying.

5. Discussion

The research conducted proved that despite the extension of the delivery time of electronic components, the material stocks of electronic equipment manufacturers increased significantly. This resulted in an even greater increase in demand and the bullwhip effect in terms of the first wave, *i.e*., the increasing demand amplitude up the supply chain. Revenues and, to a much greater extent, inventories increased. IC manufacturers were unable to meet the increased end demand due to the decisions of electronic equipment manufacturers and distributors, who also increased orders, receiving much more inquiries and having immediate sales at very attractive prices. Since supply chains are not transparent, chipmakers are unable to discern the nature of the orders they receive and distinguish which present actual final demand and which are speculative or used to build up excess inventory. Record revenues and profits of integrated circuit manufacturers, as well as financial incentives from governments seeking independence, have prompted them to increase their production capacity by investing in increased efficiency and building new factories. However, this process is not only very capital-intensive, but also time-consuming, as it takes 2-3 years to build and launch a new factory.

Hence, investment decisions from 2021 will have a real impact on increasing supply only from 2024. A significant reduction in delivery times should then be expected, which will reassure manufacturers of electronic devices and motivate them to reduce inventory levels and orders. However, it can be expected that the inventories already built will not be fully used and will have to be scrapped or resold for a fraction of the purchase value, generating losses. In turn, distributors will try to cancel their orders not only due to the reduction of purchases by electronic device manufacturers, but also due to the withdrawal from speculative purchases. As a consequence, IC manufacturers will have excess production capacity, which will lead to intensified competition, lower prices and profits, or even incur losses. It can therefore be expected that the negative consequences of the bullwhip effect will also manifest upstream in the supply chain, and the amplitude of demand will turn into an amplitude of supply. One caveat should be made here. This problem will particularly affect those producers of integrated circuits whose products have their equivalents and will not be related with a strong increase in demand, *e.g*., with electromobility or miniaturization, *i.e.,* the demand for integrated circuit structures of several nanometres.

6. Conclusions

The main aim of this article was to show the causes and consequences of supply shortages in semiconductors for the automotive and electronics industries in 2021 and it was achieved. The causes were related to the increased demand and the policy of anticipatory building stocks by electronic device manufacturers. In turn, the consequences were production restrictions or stoppages of automakers and electronics manufacturers, which resulted in financial losses or decreased profits. It has also been revealed that one of the reasons for building anticipatory inventories by electronic device manufacturer managers was based on the behaviour of panic buying. By this, the first subsidiary objective has also been achieved. The second one concerned the proposals for strengthening the resilience of supply chains to demand impulses through digitization and transparency of information and material flows. There is no doubt that avoiding or at least significantly reducing the negative effects of the bullwhip in the semiconductor and electronics industries will only be possible once the transparency of supply chains is built. Although the technical means to build such transparency already exist in the form of widely available electronic communications, practical solutions are still lacking on a global scale, comprehensively covering flows from raw materials to finished products. For many years, researchers have pointed to the transparency of material and information flows as an antidote to the negative effects of the bullwhip. Lee *et al*. (1997) point to the need to implement information sharing, *i.e*., understanding system dynamics, use point-of-sale (POS) data, electronic data interchange (EDI), Internet, computer-assisted ordering (CAO), sharing sales, capacity and

inventory data. This is aptly expressed by Ivanow and Dolgui (2022) by saying that digital technologies can improve efficiency and resilience under resource shortage by adding end-to-end visibility and flexibly reacting to fluctuation by reconfiguration of systems and resources using Industry 4.0. The conclusions presented by Adhi Santharm & Ramanathan (2022) for the automotive industry point to the need to implement digital transformation across multitier supply networks to gain visibility, particularly after pandemic shortage experiences. The problem, however, is that companies use different information systems, and the exchange of information between them, especially in the context of the dynamics of transactions carried out from sporadic to repetitive, along the entire supply chain from the extraction of raw materials to the delivery of finished products, as well as in view of the need to disclose not only their inventories but, above all, their production schedules, would require, on the one hand, to see real benefits, on the other hand, to be able to plug into the supply network on a Plug&Play basis (Urbańczyk, 2020).

Regarding research questions, all of them were answered. The reasons for the increased delivery times for electronic components were described, as well as the respond of electronics manufacturers and the consequences. Past and subsequent adverse bullwhip effects were listed, and finally, measures to reduce the harmful effects of limited availability of electronic components were presented.

In conclusion, empirical confirmation was obtained for the hypothesis indicating that shortages in the electronic components market in 2021 were due not only to increased demand for finished electronic devices but also due to the building of anticipatory inventories by electronic device manufacturers. The second hypothesis, however, turned out to be only partially true, as the implementation of panic buying practices was only one of the reasons for the increase in inventories at electronic device manufacturers during the 2021 electronic component shortages. The revealed phenomenon of panic buying in business-to-business relations in the context of the component shortage crisis would require in-depth research among supply chain managers and the impact on their decisions and the effects of those decisions.

Annex

Label	Replace by	Reason	Label	Replace by	Reason
anxiety	anxiety_	spelling	media role	social_media	aggregation
attitude		ambiguous	pandemic	plague	aggregation
Australia		country	pandemics	plague	aggregation
behavioural response	consumer_behaviour	aggregation	panic buying		keyword
China		country	perceived risk	risk	spelling
consumer behaviour	consumer_behaviour	aggregation	perceived scarcity	shortage	aggregation
consumer behaviour	consumer_behaviour	aggregation	perception		generic
consumption	consumer_behaviour	aggregation	price controls	price increase	aggregation
consumption behaviour	consumer_behaviour	aggregation	price gouging	price increase	aggregation
coronavirus	plague	aggregation	psychology		method term
Covid-19	plague	aggregation	public policy	social_media	aggregation
Covid-19 pandemic	plague	aggregation	Qatar	plague	aggregation
crisis	crisis_	spelling	resilience	resilience_	spelling
disease spread	plague	aggregation	retailing	retail	spelling
epidemic	plague	aggregation	scarcity	shortage	aggregation
fake news	fake&overload news	aggregation	shopping activity	consumer_behaviour	aggregation
food behaviour	food	aggregation	shortages	shortage	aggregation
food policy	food	aggregation	simulation		method term
food supply	food	aggregation	social learning	social_media	aggregation
grounded theory		method term	social media	social_media	aggregation
hoarding		generic	social network	social_media	aggregation
impulse buying	impulse_buying	aggregation	stocking behaviour	stockpiling_	aggregation
impulse buying behaviour	impulse_buying	aggregation	stockpiling	stockpiling_	aggregation
impulsive buying	impulse_buying	aggregation	supermarket	food	aggregation
India		country	supply chain disruption	supply chain disruption&management	aggregation
Indonesia		country	supply chain management	supply chain disruption&management	aggregation
information overload	fake&overload news	aggregation	theoretical study		method term
internet	internet_	spelling	theory of planned behaviour		method term
inventory management	stockpiling_	aggregation	viral disease	plague	aggregation
leadership		generic	viruses	plague	aggregation
lockdown	lockdown_	spelling			

Table 2. VOSviewer thesaurus

Source: Own study.

References

Adhi Santharm, B., Ramanathan, U. (2022), "Supply chain transparency for sustainability – an intervention-based research approach", *International Journal of Operations and Production Management*, Vol. 42 No. 7, pp. 995-1021.

Au, L. (2021, April 29), *Wired*, available at: https://www.wired.co.uk/article/china-microchip-autonomy-huawei (accessed 29 April 2022).

CBS News (2022), available at: cbsnews.com/news/chip-shortage-cost-us-economy-billions-in-2021/ (accessed 28 January 2022).

Chen, F., Drezner, Z., Ryan, J., Simchi-Levi, D. (2000), „Quantifying the bullwhip effect in a simple supply chain: the impact of forecasting, lead times, and information", *Management Science*, Vol. 46 No. 3, pp. 436-443.

Christopher, M. (2011), *Logistics and supply chain management*, Pearson Education Limited, Harlow.

Dejonckheere, J., Disney, S., Lambrecht, M., Towill, D. (2003), "Measuring and avoiding the bullwhip effect: A control theoretic approach", *European Journal of Operational Research*, Vol. 147 No. 3, pp. 567-590.

European Chips Act. (2022), available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

Evertiq (2021), available at: https://evertiq.pl/news/27809 (accessed 22 July 2022).

Evertiq (2021), available at: https://evertiq.pl/news/28119 (accessed 28 September 2022).

Evertiq (2021), available at: https://evertiq.pl/news/28086 (accessed 22 September 2022).

Evertiq (2021), available at: https://evertiq.pl/news/28219 (accessed 13 October 2022).

Evertiq (2022), available at: https://evertiq.pl/news/29688 (accessed 21 July 2022).

Ivanov, D., Dolgui, A. (2022), *The shortage economy and its implications for supply chain and operations management*, "International Journal of Production Research", Vol. 60 No. 24, pp. 7141-7154.

Jaeszke, Ł. (2022), *tek.info.pl*., available at: https://tek.info.pl/article/2231/1/top100_polskich_oem_2022 (accessed 7 November 2022).

Jaewon, K. (2021). *Nikkei Asia*, available at: https://asia.nikkei.com/Business/Tech/Semiconductors/South-Korea-plans-to-invest-450bn-to-become-chip-powerhouse (accessed 13 May 2022).

Lee, H.L., Padmanabhan, V., Whang, S. (1997), "The Bullwhip Effect in Supply Chains", *MIT Sloan Management Review*, Vol. 38 No. 3, pp. 93-102.

Lee, H., Padmanabhan, V., Whang, S. (1997), "Information Distortion in a Supply Chain: The Bullwhip Effect", *Management Science*, Vol. 43 No. 4, pp. 546-558.

Metters, R. (1997), "Quantifying the bullwhip effect in supply chains", *Journal of Operations Management*, Vol. 15 No. 2, pp. 89-100.

Mohammad, W., Elomri, A., Kerbache, L. (2022), "The Global Semiconductor Chip Shortage: Causes, Implications, and Potential Remedies", *International Federation of Automatic Control*, pp. 476-483.

Monch, L., Chien, C.-F., Dauzere-Peres, S., Ehm, H., Fowler, J. (2018), "Modelling and analysis of semiconductor supply chains", *International Journal of Production Research*, Vol. 56 No. 13, pp. 4521-4523.

Outlays and results in industry in 2019 (2020), *Statistics Poland*, available at: from https://

stat.gov.pl/obszary-tematyczne/przemysl-budownictwo-srodki-trwale/przemysl/naklady-i-wyniki-przemyslu-w-2019-roku,4,37.html (accessed December 2022).

Outlays and results in industry in 2021 (2022), *Statistics Poland*, available at: https://stat.gov.pl/obszary-tematyczne/przemysl-budownictwo-srodki-trwale/przemysl/naklady-i-wyniki-przemyslu-2021-roku,4,45.html (accessed December 2022).

Ovezmyradov, B. (2022), "Product availability and stockpiling in times of pandemic: Causes of supply chain disruptions and preventive measures in retailing", *Annals of Operations Research*.

Pelle, A., Tabajdi, G. (2021), "Covid-19 and transformational megatrends in the european automotive industry: Evidence from business decisions with a central and eastern european focus", *Entrepreneurial Business and Economics Review*, Vol. 9 No. 4, pp. 19-33.

Ramani, V., Ghosh, D., Sodhi, M. (2022), "Understanding systemic disruption from the Covid-19-induced semiconductor shortage for the auto industry", *Omega*, Vol. 113.

Scott, G. (2021), *https://www.jabil.com/*, available at: https://www.jabil.com/blog/global-chip-shortages.html

Statistical Bulletin No 9/2022 (2022), *Statistics Poland*, available at: https://stat.gov.pl/en/topics/other-studies/informations-on-socio-economic-situation/statistical-bulletin-no-92022,4,143.html (accessed December 2022).

Suri, R. (2010), *It's About Time*, Taylor & Francis Group, New York.

tek.info.pl (2021), available at: https://tek.info.pl/article/1222/panasonic_rezygnuje_z_produkcji_telewizorow_w_czechach/0

The White House (2022), available at: https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/

Urbańczyk, T. (2020), *The Case of The European Manufacturer of Electronic Products – Integration Experiences*, Plug & Play Supply Chain Integration Concept – IT Challenge, *35th International-Business-Information-Management-Association Conference (IBIMA)*, Seville, Spain, pp. 3044-3051.

Van Eck, N., Waltman, L. (2009), "How to normalize cooccurrence data? An analysis of soem well-known similiratiy measures", *Journal of American Society for Information Science and Technology*, Vol. 60 No. 8, pp. 1635-1651.