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Global Supply Chain Pressure and 3D Printing Investments

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Abstract

Recent events such as the pandemic have shed some light on the vulnerability of the global supply chains when they are greatly disrupted. Some firms opt to increase their in-house capacity, while some businesses resort to sourcing locally. Technology, which had been used to increase efficiency of firms, became even more important in solving and preventing supply chain risks by increasing flexibility in sourcing. 3D printing has played an important role in relieving some of the pressure from businesses. Hence, businesses might not have to choose between improving efficiency by producing or sourcing where it is cheap versus improving security by sourcing or bringing facilities closer to home. In this paper, the aim is to shed some light on the impact of global supply chain problems on investments into 3D printing start-ups. Using a Poisson regression model for investigating the hypotheses, we found that as pressure has built on the supply chains, businesses made more investments in the 3D printing technology in order to navigate through the volatility. The future research could expand to cover more technology and time period. We hope that the paper will highlight the importance of 3D printing technology in businesses when supply chain disruption occurs.

Keywords: supply chain, disruption, 3D printing, Covid, investment, resilience.

I. INTRODUCTION

The Covid-19 outbreak that originated in Wuhan, China spread quickly throughout the world causing supply chain disruptions and a halt in many operational activities as people were quarantined and borders were closed. The pandemic, as a result, showed how vulnerable supply chains can be. Although events such as the tsunami in Japan in 2011 exposed some firms to unexpected disruptions, the pandemic outbreak was the first recent global-scale disruption. Companies simply did not prepare or have any guidance for this type of crisis. As Bier et al. (2020) pointed out, in many cases firms only realize the vulnerability of their supply chain when a disruption has occurred. Many parts, products and services were delayed getting to the buyers, creating shortages, increasing costs (Riddalls & Bennett, 2002) and hurting company income (Hendricks & Singhal, 2005). In addition to income, other dimensions of supply chains including lead time, demand changes, and production performance also have had an impact from the pandemic (Moosavi et al., 2022). The impact on supply chain can be short-term and long term (Khan et al., 2022). As supply chains grow into global scale, the negative impact may increase in severity because the disruption may spread through the system instead of being contained to just the initial firm (Scheibe & Blackhurst, 2018). Therefore, research on supply chain disruptions has attracted an increasing amount of attention in recent years as the search for growth and efficiency drove the world to become interconnected.

The use of 3D printing or additive manufacturing has gained momentum before the start of the pandemic. In manufacturing, due to many benefits such as flexibility and

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cost reduction, 3D printing is used for new product development, design and prototyping and small-scale production, supporting and complementing large scale production, which uses other Industry 4.0 digital technologies (e.g., AI controlled robots). As a result, 3D printing technology can transform the way firm organize their innovation and production operations (Hahn & Massini, 2024). In the health sector, 3D printing helped relieve the shortages in personal protective equipment (PPE) (Niranjan et al., 2022). As such, 3D printing technology has the potential to alleviate social issues and lead to profound societal changes (Marić et al., 2023). Innovation in 3D printing technologies – printers and materials – continues at fast rates. Companies developing 3D printing technologies are investing in new designs and new materials, for both industrial and domestic use. The 3D printing industry has grown from just printing parts or prototypes to printing a house (Smart, 2021) or a car (Kermeliotis, 2014). The opportunities are endless. Forger (2019) believed that 3D printing is moving to a critical mass. Rayna and Striukova (2021) also believed that 3D printing technologies are not restricted to multinationals and large corporations. However, there is a gap in the literature on whether supply chain pressure leads to increased investments into 3D printing.

This paper will empirically investigate the impact of the increase in global supply chain pressure on investments into 3D printing start-ups. We will first explore the literature review on supply chain disruption, provide an overview of 3D printing, and explain transaction cost theory. We then provide our hypotheses development. Then we will explain the data collection process and methodology. Next we discuss our analyses and results, and finally draw conclusions for future research.

II. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1. Supply Chain Disruption

Disruptions are events occurring in a supply chain (Wu et al., 2007). Although the disruption can be a micro risk affecting one or a few companies, some disruptions have an impact on many companies at the same time (macro risk). Golan et al. (2020) explained that when one supply chain fails, other supply chains are also directly and indirectly affected. In general, disruptions in supply chains are caused by events with a low probability of occurrence and very high impact (Shen & Sun, 2021). These disruptions include not only natural hazards (Wakolbinger & Cruz, 2010) but also operational risks, risks arising from natural hazards, and political instability. In other words, the disruption can be manmade such as a legal dispute which halts operations (Bier et al., 2020) or terrorism. These disruptions can also have financial impacts in both the short-term and the long-term (Tang, 2006).

2.2. 3D Printing

3D printing received much attention because of its flexibility to customize and respond quickly to any disruptions. Its ability to assist innovation, new product design, and development can result in faster manufacturing periods and huge reductions in costs. In 3D printing, which is a type of additive manufacturing, materials are bonded or joined to create objects. It is different from several subtractive traditional manufacturing processes like cutting, carving, polishing, drilling, milling, and lathing. Rose et al. (2016) and Menon et al. (2020) explained that additive manufacturing and other digital technologies have recently made remarkable advancements that are changing how production and innovation are carried out. Öberg et al. (2018) stated that 3D printing technology may change the way companies operate their businesses. Durach et al. (2017) explained that additive manufacturing technology have many applications including rapid prototype manufacturing, tooling, and spare part production. These benefits have spurred interests in additive manufacturing as an emergency solution for supply chain disruptions (Peron et al., 2022). Laplume et al. (2016) stated that the advancement of 3D printing technologies and their wider adoption could change the geographical configuration of production systems. For businesses looking to use this technology in their production processes and impact supply chains, a variety of materials, including metal, plastics, polymers, and food ingredients, are widely available. For example, the 3D printing technology even successfully printed pizzas (Garfield, 2017). Additive manufacturing has been used in variety of industries, organizations, and business including medical industry (hip implant), the air force (replacement parts), and General Electric (fuel nozzle) (The White House, 2022). Due to this, Mohr and Khan (2015) explained that 3D printing technology has emerged as one of the most disruptive innovations to impact the global supply chain and logistics industry.

2.3. Transaction Cost Theory

The transaction cost concept was developed by Coase (1937) and later Williamson (1985). The theory uses transaction costs to explain when transactions occur within the firm (an economic unit) or in the market. If transaction costs of producing goods or services in the market are lower than internal production cost, then activities should occur outside firms' boundaries rather than within firms. However, if transaction costs in markets are higher than internal production costs, then activities should occur within the firm's boundaries. By investing in 3D printers, firms believe that costs are lower than in markets.

2.4. Hypotheses Development

Supply chain disruption has become a major problem when the Covid-19 pandemic started. Shanker (2020) reported that almost 75% of supply chain executives indicated major supply chain disruptions in 2020 due to Covid-19, with almost half reporting they did not have a plan in place to deal with such a disruption. Sherman (2020) reported that 94% of the Fortune 1000 were seeing coronavirus supply chain disruptions. Golan et al. (2020) pointed out that the Covid-19 pandemic clearly shows the lack of resilience in supply chains. Supply chain resilience refers to the adaptive capability of supply chains to prepare for and/or respond to supply chain disruptions (Tukamuhabwa et al., 2015). Chen et al. (2013) explained that supply chain collaboration can effectively reduce supply chain risk. As a result, supply chain integration is one of the effective strategies in risk management. Innovation is also important in reducing risks as Kwak et al. (2018) explained that innovation positively affects risk management capabilities, such as robustness and resilience in global supply chain operations. 3D printing is one innovation that should help with supply chain disruption management. Therefore, we propose the following hypothesis.

H_1: the higher the global supply chain pressure, the greater the number of 3D printing investments.

Covid caused a strain in global supply chain in different ways since people were locked down and isolated, and labor shortages occurred (Singh et al., 2021). Moreover, though some of the work could be done from home, many manufacturing jobs could not and that led to a dramatic decrease in production and operations which, in turn, created shortages. Not only was people's movement restricted, material transportation was as well. This compounded the problem of shortages. In addition, because people were prohibited from (or avoided) going out despite needing their daily consumer products, consumers purchased these items in larger quantities (Moosavi et al, 2022). Besides the demand from consumers, the health sector was also in need of greater amounts of medical equipment such as masks, gloves and ventilators.

In the last few decades, advances in technology and the falling cost of the internet allowed firms to relocate their business services to offshore locations (Dossani & Kenney, 2007). There was an emergence of offshore outsourcing of services and business service providers (Manning et al., 2018). As a result, global value chains have been reconfigured (Laplume et al., 2016). However, the Covid-19 pandemic has changed the notion of what constitutes a lean and efficient supply chain. Companies have increasingly considered moving their operations back or closer to home country. In other words, reshoring and nearshoring have become a more prevalent strategic decision. Integrating 3D printing in manufacturing can reduce the number of production steps and the number of parts used and as a result can lead to a reduction in costs. This cost reduction may compensate for higher wages in developed countries. As pointed out in transaction cost theory, transactions occur within firms' boundaries. This may contribute to even greater levels of reconfiguring of dispersed global supply chains (Strange & Zucchella, 2017). In addition, localizing the production can increase flexibility and resiliency to supply chains (Shanker, 2020).

On the other hand, as we pointed out earlier, the pandemic was the first recent event that caused a global-scale disruption in which businesses were not prepared for the situation. As a result, businesses may need time to rethink how to use their resources to deal with supply chain disruption. On the contrary to what transaction cost theory predicts, supply chain disruptions could actually reduce the amount of investment in 3D printing. This could be because firms might opt to save some money and cut down investments in order to weather out the crisis. Or the pandemic itself might cause increased uncertainty which interfered with the complex process of making corporate financial investments. Choong et al. (2020) pointed out that 3D printer owners around the world, from hobbyists to industry users, have been amplifying their commitment with innovative solutions to help in the global Covid-19 supply efforts. This could imply that there is an increase in usage by 3D printing community. However, the 3D printing investments by businesses themselves might not occur right away. Given that two opposite hypotheses are conceivable, we developed the hypotheses as follows.

H_{2A}: the disruptive effects of the Covid-19 pandemic leads to an increase in 3D printing investment.

H_{2B}: the disruptive effects of the Covid-19 pandemic leads to a decrease in 3D printing investment.

III. RESEARCH METHODOLOGY

3.1. Data

3.1.1. The number of 3D printing investments

We use the data source Crunchbase.com. Crunchbase is a platform that is known for a focus on technology-oriented start-up firms. Hence this data source had a pertinent focus for the current research. We screened for firms on Crunchbase that were categorized by Crunchbase as being in the 3D printing industry category and that had received a financial investment.

Some reported investments from Crunchbase were very small, so we only used the investments that are greater than $50,000 in order to have the same nature of investments in the dataset. A total of 310 observations was obtained from Crunchbase.com. The data cover the time period from January 1st, 2012 through September 30th, 2023. From this we calculated the number of investments into 3D printer companies on a per-month basis. This monthly county was used as our dependent variable.

3.1.2. Global supply chain pressure index (GSCPI)

GSCPI was developed by applied macroeconomics and econometrics center (AMEC), federal reserve bank of New York. This is a monthly data series that was launched in May, 2022. The index was created in an effort to assess the intensity of global supply chain disruption (FRBNY, 2022b). The FRBNY (2022b) explained that "assessing the intensity of this issue has posed a challenge because conventional measures are largely focused on specific dimensions of global supply chains." According to the federal reserve bank of New York website (2022a, b), the index integrates over 27 variables from commonly used metrics. It uses data from both transportation and manufacturing sectors to track pressure from 1997 to the present.

The transportation sector data include the Baltic dry index (BDI), the Harper index, and airfreight costs indices from the U.S. Bureau of Labor Statistics. The manufacturing sector data uses several supply chain-related components from purchasing managers' index (PMI) surveys focusing on manufacturing firms across seven interconnected economies: China, the euro area, Japan, South Korea, Taiwan, the United Kingdom, and the United States. These also are monthly data series and we collected the data for the period of January 2012 to September 2023 to match with the 3D printing investment data.

3.1.3. Covid

On March 12th, 2020, the world health organization (WHO) declared the global spread of the Covid-19 the pandemic. As a result, we added a dummy variable to reflect the situation. We used zero to represent the period before the pandemic and one to be during or after March 2020. We began to have Covid variable as one in March, 2020.

3.1.4. Financial conditions impulse on growth (FCI-G)

Since 3D printing investments could occur because the economic environment is simply favorable, we introduce a control variable which is an indicator for the investment climate. We used the financial conditions impulse on growth (FCI-G) variable to represent the investment climate. This variable is a monthly index which we retrieved from the federal reserve bank (Ajello et al., 2023). The FCI-G index aggregates changes in seven financial variables—the federal funds rate, the 10-year Treasury yield, the 30-year fixed mortgage rate, the triple-B corporate bond yield, the Dow Jones total stock market index, the Zillow house price index, and the nominal broad dollar index—using weights implied by the FRB/US model and other models in use at the Federal Reserve Board (Ajello et al., 2023). These models relate households' spending and businesses' investment to changes in these financial variables. That is changes in financial conditions are related to real GDP growth (Ajello et al., 2023). Positive changes in FCI-G denotes headwinds to GDP growth (tightening) and vice versa (Ajello et al., 2023).

3.2. Methodology

We used a Poisson regression model for investigating the hypotheses. This model is commonly used when the dependent variable is a count. We used robust standard errors which are robust to mild levels of model misspecification. The coefficients represent estimates of the linear relationships between the predictors and the logarithm of the counts. Here a coefficient of Z means that a one-unit increase in the predictor variable is associated with an approximate expected increase of Z percent in the outcome count of the dependent variable (when Z is small). Our predictors are GSCPI, Covid, and FCI-G given FCI-G as a control variable. The dependent variable for our model is a count variable which indicates the number of 3D printing investments per month.

IV. RESULTS AND DISCUSSION

4.1. Results

Table 1
The Results of the Poisson Regression Model

DCount	Coef.	Robust Std. Err.	z	p-value
GSCPI	0.1677	0.0486	3.45	**0.001**
Covid	-0.2802	0.1079	-2.60	**0.009**
FCIG	0.1960	0.0771	2.54	**0.011**
_cons	2.1205	0.0575	36.86	**<0.0001**

Table 1 shows the results of the Poisson regression. We can interpret the results as follows. For the first hypothesis, as GSCPI increases by one unit, the count of the number of 3D printing investment increases by 18.1%. The p-value here is 0.001 which means it is significant. hypothesis 1 is supported. That is the more the global supply chain pressure increases, the greater the number of investments were made into 3D printing start-ups. Peron et al. (2022) believes that additive manufacturing has been shown to be very effective in guaranteeing the restoration and reconstruction of the supply chain. Likewise, Oldekop et al. (2020) explained that digitally organized logistics have played a role in mitigating negative impacts. Therefore, businesses invested more in 3D printing.

For the second hypothesis in which we looked at the Covid variable, we can interpret this as the number of 3D printing investments decreases by 24.4% after the beginning of the pandemic compared to before the pandemic. The p-value here is 0.009 which is significant. That means hypothesis 2B is supported. UNCTAD (2021) states that the lockdowns around the world in response to the Covid-19 pandemic slowed down existing investment projects. Companies reassessed new investment projects as a result. Therefore, even though 3D printing could help alleviate the impact of the pandemic, there seems to be a pause in investment for companies to rethink their strategies.

Lastly, our control variable FCI-G has a coefficient of -.1960 which means when there is one unit increase in FCI-G, which signaled the slowdown in future GDP, the number of the 3D printing investment counts increases by 21.6%. The *p*-value here is less than 0.011 which is significant. As recession looms, companies could reduce costs by investing in technology such as 3D printing. It could reduce labor cost, transportation cost, material cost and waste. Companies seem to increase the number of investments so that they will be better equipped for economic slowdowns or to take advantage of more favorable market conditions.

V. CONCLUSION

5.1. Conclusion, Analysis, Limitations, and Future Research

This paper empirically showed that as supply chain pressure grew, we observed higher numbers of 3D printing investments. This could be because firms see the benefits of 3D printing as a tool for supply chain resilience. However, the 3D printing investments themselves slowed down during the Covid pandemic even with many benefits that the 3D printers have to offer. Adopting 3D printing in the production process might not occur overnight. Therefore, managers should therefore plan in advance if they want to use the 3D printing to reduce the effect of the supply chain disruption.

The White House (2022) launched additive manufacturing forward (AM Forward) which is a compact among large manufacturers to assist small U.S.-based suppliers increase their use of 3D printing in order to improve supply chain resilience. In addition to the speed and flexibility of production that the 3D printing brings, it hopes to help make the U.S. economy less dependent on inputs from abroad. This initiative shows it is important to increase supply chain resilience.

In terms of future research, this paper takes a look at general supply chain pressure and has Covid as a specific event. Future research can include more events in order to observe the investments. In addition, it can expand to other technology which could help improve supply chain resilience. Lastly, more data can be collected in order to cover more periods after the pandemic was ended.

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