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A Pooling Test for Increasing COVID-19 Testing Capacity and Cost Saving

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Abstract

In response to the pandemic of COVID-19, a strong test capacity is fundamental. A pooling test with a half-interval search method was proposed to enhance the test capacity and to save test costs. Half-interval search splits the test samples into halves, and each half is tested separately. If the half pooling sample is negative, no more test is needed for this half. Otherwise, it will be split again until the positive samples are identified. Due to the fact of low positivity rate in the test pools, this strategy can increase the test capacity and reduce test cost, comparing with the one-sample-one-test method. A Python program was generated to simulate tests to be saved. In a case study of a 100 patient sample pool with a positivity rate of 5%, which is suggested by WHO for sufficient tests, the test volume could be reduced to 20-50 from 100. As a result, the test cost could be saved by 50-80%.

Key words: COVID-19, collective test, half-interval search, testing capacity, and cost-saving

1. Introduction

COVID-19 has been out since the end of 2019 and has spread all over the world. It is currently still a very serious pandemic. Up to now (August 4th, 2020), more than 18 million people have been infected, and more than 691,000 people have died worldwide. In the United States, 4.6 million people have been confirmed, and 155,204 people have died (Website, n.d.-a; Website, n.d.-b). To control this pandemic, it is important to find infected patients with COVID tests and quarantine them. COVID test can detect SARS-CoV-2 by molecular diagnosis, antigen detection diagnosis, and serological diagnosis. Molecular diagnosis detects SARS-CoV-2 nucleic acids from human specimens. Antigen diagnostic test detects SARS-CoV-2 antigens directly from clinical specimens. The SARS-CoV-2 serological diagnostic test identifies antibodies (e.g., IgM, IgG) to SARS-CoV-2 from clinical specimens (*[No Title]*, n.d.-a). The most efficient and popular test is the molecular diagnostic test or nucleic acid test.

A positivity rate of COVID-19 is defined as total confirmed cases as a share of the total number of people tested, or the number of positive in the number of tests performed. It is an important parameter to track the pandemic. If the positivity rate is high, it means the tests are mostly conducted in the sickest patients. The testing is insufficient to find infections that may exist and cannot track outbreaks accurately. The WHO suggested a 5% positivity rate for the test (*Track Testing Trends - Johns Hopkins Coronavirus Resource Center*, n.d.). This means that a large testing capacity becomes necessary to slow and stop the spread of the disease in many countries. In addition, the cost of the large test volume will be huge. In the United States, a single test may cost hundreds to thousands of dollars (Kliff, 2020). Enhancing the test capacity and saving the test cost is always significant to save time and protect people from the pandemic quickly.

A normal medical practice to test COVID-19 is to use one test for one patient. With the fact that a low positive rate of COVID-19 cases among tests (around

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6% in San Diego County, California, USA) (*[No Title]*, n.d.-b), we could pool multiple patient specimens to do one test (pooling test) to save test cost and speed up the tests. The saving can be defined as the difference between the tests needed in a one-sample-one-test strategy and the total test number in a pooling test strategy.

Here, a principal of a half-interval search or binary search can be applied to find the feasibility of a pooling test to increase test capacity and saving the cost (Williams, 1976).

2. Method

The half-interval search begins by dividing a list of patients (a pool of patient samples) into two divided parts with an equal number of elements (patient samples). Here, a "True" Boolean represents a positive patient sample, and a "False" Boolean represents a negative patient sample. If the positive sample is in a divided part, then this part is continued to be divided into another two divided parts until the positive sample is identified. If the positive sample is not in the divided part, then this part is a collection of samples with all negative and no more tests are needed. By doing this, the algorithm eliminates the half in which the positive sample cannot lie in each iteration. The total test number for this list of patients can be calculated by counting the iteration numbers.

A program was written based on the half-interval search to calculate the total test number in a pooling test strategy and its savings (a difference of tests between a one-sample-one-test method and a pooling test method) in the tests.

Here, the total test number in the pooling test will depend on the positive sample distribution in the sample pool. Generally, positive samples are distributed in the pool randomly. Then, the total test number will be varied in every single running of the program due to the different positive sample locations in the pool. To estimate a range of this variation, two other sample distributions are proposed.

Technically, when all positive samples are distributed consecutively in a sequence (called collective distribution) in the sample pool, most divided half-partial will be negative in the half-interval search. Thus, fewer tests are needed to find out all the positive ones. Reversely, if all positive samples are distributed evenly (called even distribution), then, more tests are needed to find them. In view of these considerations, three experiments with different sample distributions, random, collective, and even distributions, were listed in the program.

2.1 Programming

Python is used to generate a program with a half-interval search to optimize the pooling tests for COVID-19. The program was designed as below.

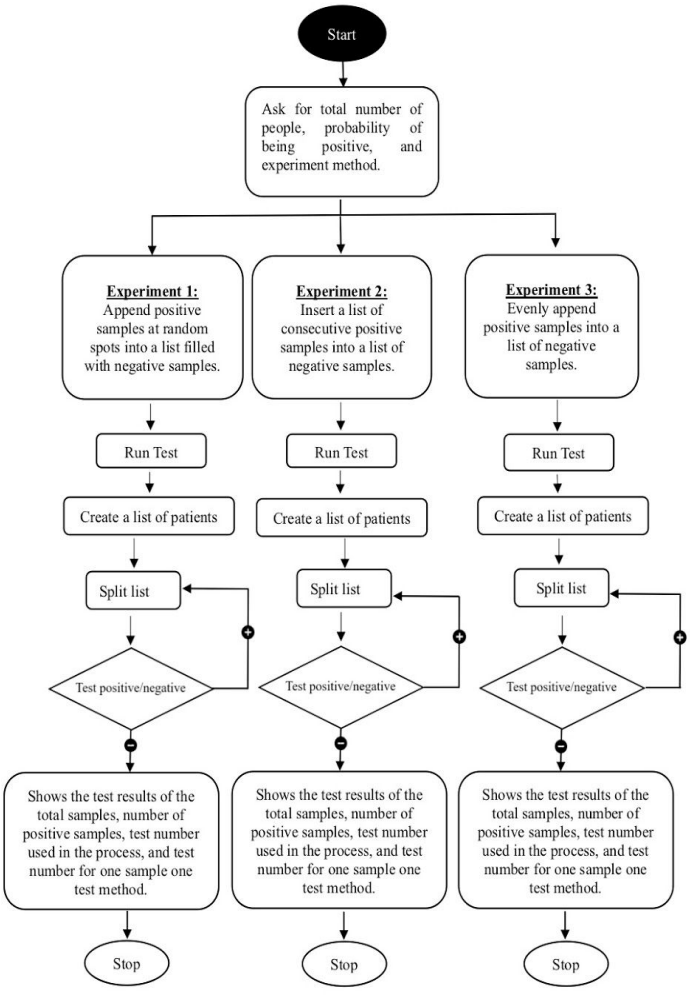

Figure 1. Overview of Python code.

(The program was uploaded to Git Hub as shown: https://github.com/EricQXu/Efficient_COVID_Test.git.)

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2.2 Application

We set a sample pool of 100 patients. The positive sample was distributed in several experiments as stated in the flow chart. With different positivity rates in the tests, the program looks for how many times of splits are needed to find out all positive patient samples, and then count the test number during the process.

3. Results and Discussion

3.1 A threshold of positivity rate in the pooling test.

From the above experiments with different positive sample distributions, the data was plotted in the figures below

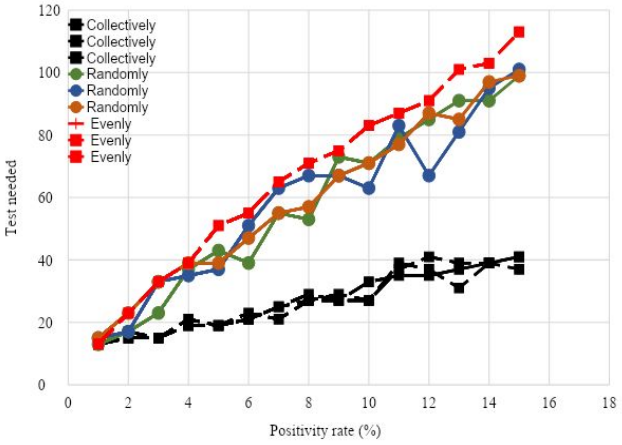

Figure 2. The test needed in a pooling test with different positivity rate

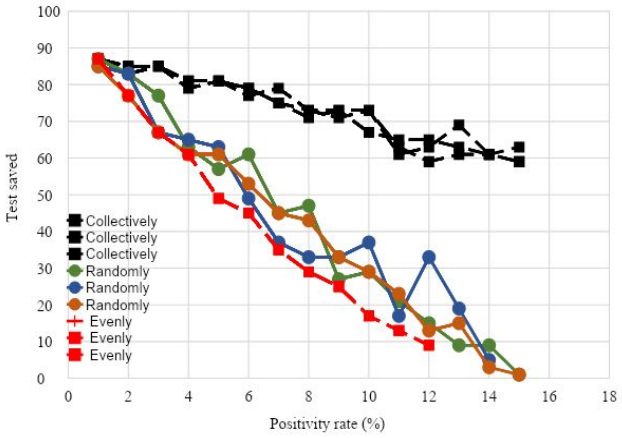

Figure 3. The test saved in a pooling test with different positive ratio

From the figures above, we can find that the tests needed or the test saved in a pooling test are strongly dependent on the positive sample distribution. At a fixed positivity rate (saying 5%), the tests needed could be any number from 20 to 50.

When the positivity rate increases, the tests needed are increased quickly, and the tests saved are reduced. For an even distribution in a pooling test, once the positivity rate reaches 12%, the tests needed will be close to 100, and no test is saved at all. This can be set as a threshold value of the positivity rate with a conservative evaluation for the pooling test. Even though, at this rate, it can still be saved 60-65 tests if the positive samples are distributed collectively.

3.2 The tests saved in the current pandemic situations

Currently, the positive ratio in San Diego, California is around 6% (updated July 31st, 2020) as shown in Figure 4 (*[No Title]*, n.d.-b).

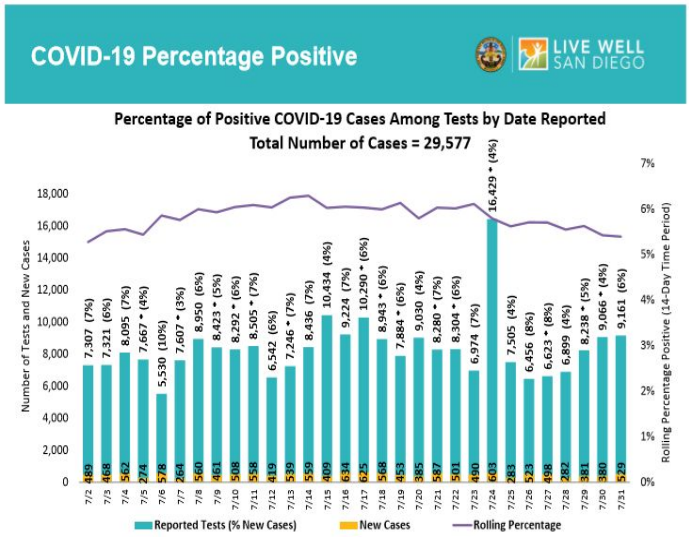

Figure 4. Percentage of positive COVID-19 cases in San Diego

The positive ratio in the United States is 10% from the published data (updated Aug. 2nd, 2020) by CDC as shown in Figure 5 (CDC, 2020). The positivity rates worldwide are varied from 0.3% in New Zealand to 28.3% in Argentina (updated July 31st, 2020) as shown in Figure 6 (*Share of Total COVID-19 Tests That Were Positive*, n.d.). Most countries show a positivity rate of less than 10%. Only three countries, Argentina, South Africa, and Indonesia, are more than 10%.

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Figure 5 Percentage of positive COVID-19 cases in the USA

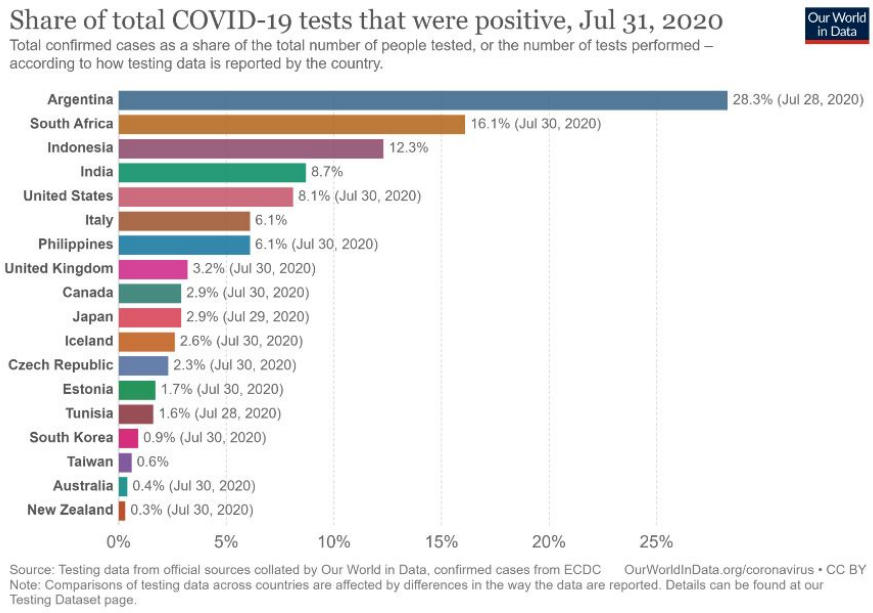

Figure 6 Percentage of positive COVID-19 cases worldwide

From the analysis of the positivity rates locally, nationally, and globally, we can see clearly that a pooling test has a strong potential to enhance the test capacity and save the test cost. Nationally, the positivity rate is 10% now, it could save around 20% tests if the pooling test is applied. If we follow WHO suggestion to reach a 5% positivity rate with more tests, then we can cast a wide enough net to identify COVID-19 cases as much as possible to track and stop outbreaks. In this situation (5% positivity rate), a pooling test strategy could save at least half the cost as shown in Figure 3.

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4. Conclusion

A pooling test method was proposed for increasing COVID-19 test capacity and saving the test cost. A Python program with a half-interval search was used to verify its feasibility. For a pooling test with 100 samples, the test volume could be reduced from 100 to 20~50, and the test costs could be saved by 50-80% for a positivity rate of 5%, which is suggested by WHO.

The total test number in the pooling test will depend on the positivity rate (how many positive samples in the pool), and the distribution of the positive sample in the pool.

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APPENDIX

A1. The positive samples are randomly distributed in the sample pool. For each positivity rate, the program was run for three times. The test results are listed in table 1.

Table 1: The tests saved with a positive sample distributed randomly in the sample pool

Positivity rate (%)	Tests Needed	Test Saved
1	13	87
	15	85
	15	85
2	17	83
	17	83
	23	77
3	23	77
	33	67
	33	67
4	37	63
	35	65
	39	61
5	43	57
	37	63
	39	61
6	39	61
	51	49
	47	53
7	55	45
	63	37
	55	45
8	53	47
	67	33
	57	43
9	73	27
	67	33
	67	33
10	71	29
	63	37
	71	29
11	79	21
	83	17
	77	23
12	85	15
	67	33
	87	13
13	91	9
	81	19
	85	15
14	91	9
	95	5
	97	3
15	99	1
	100	0
	99	1

Here, the tests needed in a fixed positivity rate are varied. This is because the positive and negative patients were distributed randomly in the sample pool.

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A2. The positive samples are distributed evenly in the sample pool. The results are listed in table 2.

Table 2: The tests saved with a positive sample distributed evenly in the sample pool.

Positivity rate (%)	Tests Needed	Test Saved
1	13	87
	13	87
	13	87
2	23	77
	23	77
	23	77
3	33	67
	33	67
	33	67
4	39	61
	39	61
	39	61
5	51	49
	51	49
	51	49
6	55	45
	55	45
	55	45
7	65	35
	65	35
	65	35
8	71	29
	71	29
	71	29
9	75	25
	75	25
	75	25
10	83	17
	83	17
	83	17
11	87	13
	87	13
	87	13
12	91	9
	91	9
	91	9
13	101	-1
	101	-1
	101	-1
14	103	-3
	103	-3
	103	-3
15	113	-13
	113	-13
	113	-13

Here, the tests needed in a fixed positivity rate are all the same in the three runs. In the experiment, there is the least chance to have a split part with all negative samples, because of the even distribution. This leads to the most tests needed at a fixed positivity rate in the pooling test. At a positivity rate of 12%, only 9 tests can be saved. And, at a positivity rate of 13%, it even takes one more test than the one-sample-one-test method.

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A3. The positive samples are distributed collectively in the sample pool. The results are listed in table 3.

Table 3: The tests saved with a positive sample distributed collectively in the sample pool

Positivity rate (%)	Tests Needed	Test Saved
1	13	87
	13	87
	13	87
2	17	83
	15	85
	15	85
3	15	85
	15	85
	15	85
4	21	79
	19	81
	19	81
5	19	81
	19	81
	19	81
6	21	79
	21	79
	23	77
7	25	75
	25	75
	21	79
8	29	71
	27	73
	27	73
9	27	73
	29	71
	27	73
10	27	73
	27	73
	33	67
11	37	63
	39	61
	35	65
12	41	59
	37	63
	35	65
13	39	61
	31	69
	37	63
14	39	61
	39	61
	39	61
15	37	63
	41	59
	41	59

Here, positive samples are distributed collectively in sequence as a group. However, this positive group can be at any part of the list of patient samples. Then, when the list of samples is split, sometimes, it may split in the middle of the group, and sometimes it may not. This brought some small variation for the test needed at a fixed positivity rate as listed in Table 3. In this experiment, there is the most chance to have a split part with all negative samples, which makes the least tests needed at a fixed positive ratio in the pooling test. At a positivity rate of 12%, there are 59-65 tests can be saved. And, at a positivity rate of 13%, the saved tests are around 61 to 69.

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An Overview of the Evolution of Modern Macroeconomic Theories

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Abstract

This paper examines the evolution of macroeconomic theories from the 18th century to present with special attention to three schools of economic thought: Classical, Keynesianism, and Monetarism. The manuscript starts off on giving a short analysis on the Great Depression and how it sparked numerous changes in macroeconomic policies. Then, the Classical Economic Theory is introduced, and its shortcomings are examined through the Panic of 1873. Next, the paper's focus will shift to a deeper analysis on the causes, impacts, and the recovery of the Great Depression and the effects it had on the United States economy. Keynesianism and the benefits of fiscal policy are introduced and reasons for the rejection of the Classical Economic theory are explained. William Phillips' Phillips Curve is then introduced and connections between Phillips' theory and Keynes' theory are made. Lastly, the paper will examine the effects of monetary policy in the 1970s and the recent Great Recession of 2008. Most importantly, the reasons modern economists like Friedman oppose fiscal policy and Keynesianism are interpreted. From the works of these economists, the central argument of the paper advocates for the fact that we can no longer rely on the Classical Economic theory during times of economic crisis. The modern economy should be observing both Keynesianism and Monetarism; we should be pursuing expansionary fiscal policy during times of downturns and contractionary monetary policy during times of economic boom

Keywords: Economics, Keynesianism, Monetarism, Classical Economics, Macroeconomics

1. Introduction

In the 1930s, the world suffered from the worst economic downturn in history known as the Great Depression. Economists conceded that the Great Depression began in the United States on October 24, 1929, when the stock market suddenly crashed as ambitious investors altogether sold approximately 12.9 million shares. Five days later on October 29, 1929, another 16 million shares were sold as the stock market further collapsed, paralyzing Wall Street investors as the nation never saw such an unprecedented and precipitous financial crisis since its industrialization (Onion et al., 2020, *Great Depression History*). The unexpected destruction of the world-renown financial sector disintegrated worldwide consumer confidence, and consumption and investment in many countries declined rapidly, leading to reduced levels of output and sharp decreases in the price level. As a result of the massive decreased demand for goods and services, firms were forced to discharge their workers and cut wages on their remaining workers. By 1933, the global gross domestic product had fallen by 26.7% and the global unemployment rate reached its peak at 24.9%. The United States, however, has suffered even worse with a drop in the real gross domestic product by 30% and a decline in the price level of 33% (Pells & Romer, 2019).

The Great Depression proved to be an essential part of American history; the destructive effects of this unanticipated economic crisis have sparked numerous debates between economists and formed profound changes in major macroeconomic theories. For long, economists depended on Adam Smith's theory of the "Invisible Hand," which for a market economy suggests that there exist invisible forces in an economy that prompt markets to move towards

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an equilibrium. Individuals should follow their own interests and the economy would eventually "self-correct" over time, without the need to accentuate or rely on fiscal and monetary policy (Majaski, 2020). While Smith's theory had been regularly observed in the American economy throughout the 19th century, the Great Depression and the periods of stagflation later observed in the 1970s provoked new insights on the extent to which Smith's theory could be applied to the modern economy.

During the peak of the Great Depression, President Herbert Hoover enacted economic policies with the intention to reduce the severity of the depression, with most of his policies centering around reducing unemployment, continuing production, and opposing direct federal intervention. However, Hoover's response to the Great Depression was generally viewed as limited and unprepared, as he severely underestimated the scope of the depression. Despite the resilient efforts put forth by President Herbert Hoover, none of his policies seemed to bring the economy out of the depression and he was soon trounced by President Franklin D. Roosevelt (Corbett et al., 2014).

Unlike Hoover who was a direct supporter of classical economics, Roosevelt followed advice from economist John Maynard Keynes through his letter "An Open Letter to President Roosevelt" in 1933 that advocated for the establishment of fiscal policy and government programs to combat the Great Depression. Keynes challenged the classical economists, arguing that prices and wages do not always adjust to current economic conditions; therefore, the only solution to the Great Depression is to rely on active fiscal policy to encourage spending. Ultimately, Roosevelt took Keynes' advice and his New Deal Program prospered in repairing the economy. Economists accepted Keynesianism and deemed Keynes as a turning point in the evolution of macroeconomic theory.

However, as time progressed to the 1970s, the United States economy suffered from unprecedented levels of stagflation - simultaneous high levels of inflation and unemployment. It was then economist Milton Friedman accentuated the importance of the Federal Reserve in controlling the nation's money supply, rejecting fiscal policy through the Crowding Out Effect and William Phillips' theory of inflation and unemployment in the long run. The practice of controlling money supply, known as Monetarism, was then widely practiced in the 1980s and beyond by President Ronald Reagan and other monetarists.

Nevertheless, while many economists thought that the Federal Reserve can maximize benefits and promote economic growth, it is not the sole solution to conquering economic catastrophes. As evidenced by the failure of banks to manage mortgages and comply with lending policies, the Great Recession of 2007-2009 proved that Keynesianism and effects of fiscal policy are still very much relevant to the modern economy.

Economists have come to the realization that the global economy is not as simple as what the classical economists had suggested. Simply waiting for prices and wages to adjust to the current economic conditions no longer proved to be a wise choice to mobilize stability. The modern economy should be observing both Keynesianism and Monetarism; we should be turning our attention to expansionary fiscal policy during times of downturns and contractionary monetary policy during times of economic boom. When these policies are applied efficiently, the economy will observe immediate short-term effects and stable monetary growth in the long run.

To understand the limitations of the Invisible Hand, and the conditions that led to the Great Depression, we need to first examine the Classical Economic Theory. The focus would then proceed to an analysis of Keynesianism and the benefits and shortcomings of fiscal policy during the Great Depression. Lastly, an analysis of the effects of monetary policy during the 1970s and the recent Great Recession of 2008 will be conducted.

2. The Classical Economic Theory

The Classical Economic Theory originated in Britain in the late 18th to early 19th century after Adam Smith's proposal of the "Invisible Hand Theory." Some other founding fathers of this economic theory are Jean-Baptise Say, David Ricardo, James Mill, John Stuart Mill, and Thomas Robert Malthus. In short, the Classical Theory suggests that an economy is better off when

individuals follow their self-interest and engage in free trade and free competition (Young, 2020), as Adam Smith once said: "Consumption is the sole end and purpose of all production; and the interest of the producer ought to be attended to, only so far as it may be necessary for promoting that of the consumer" (Kilcoyne, 2019).

Classical economists support the claim that any type of government intervention would severely harm the economy and discourage long-run economic growth. When examining the economy as a whole, classical economists believe that when resources are used and exploited efficiently, the economy would always operate at its natural rate/potential output and maintain a static unemployment rate of around 4%-5%. Classical economists insist that prices and wages are always flexible and therefore would adjust quickly to any short-run changes in the economy. If the economy is producing below its potential output, prices and wages would fall and production would increase until the economy reaches its potential. Vice versa, if the economy is operating beyond its potential output, inflation will soon set in and prices and wages would rise, decelerati_ ıe rate of production and shifting the economy back to its potential output (Willis, 2017). Altogether, these forces in the economy make up the two components that are represented in the most conventionalized and idealistic macroeconomic model: aggregate demand and aggregate supply.

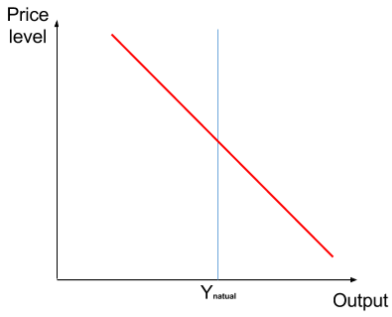

Figure 1: classical economists insist that aggregate supply (blue curve) is vertical; this economy will operate at Y(natural) in normal circumstances.

Aggregate demand represents the absolute demand for all finished goods and services in the economy at each price level; it comprises consumer spending, investment spending, government expenditures, and net exports. Any major changes in these four components would shift the aggregate demand curve. As shown in figure 1 above, the down sloping red line represents aggregate demand. When graphed on a real gross domestic product and price level chart, aggregate demand will always be down sloping from the economic law that there will always be more goods and services demanded at lower price levels than higher price levels. Aggregate supply shows the economy's total output, or the number of goods and services businesses are willing to supply at different price levels. Components of aggregate supply are not fixed, but in the modern economy, changes in taxation, technology, prices, wages, and inflation are known to shift the aggregate supply curve (Kenton, 2020, *Aggregate Supply*). The shape of the aggregate supply, however, was among the debates of many economists during the 19th and 20th centuries. While many views aggregate supply as an upsloping curve that represents a positive relationship between changes in price level and output, classical economists had distinctive interpretations of the aggregate supply curve. For more than a century, classical economists presumed that aggregate supply is vertical, showing no tradeoffs between an economy's output and price level (Pettinger et al., 2019). When graphed the aggregate demand and aggregate supply together, a healthy economy would operate at the intersection of these two curves, known as the macroeconomic equilibrium. The vertical aggregate supply indicates that an economy will always produce at its potential output (Y* in Figure 1); therefore, the classical theory indicates that aggregate supply is always fixed and that any short-run changes in the economy will only prompt shifts in aggregate demand.

Undoubtedly, the classical economists brought profound changes to the political and economic systems of many western countries. As the theory was introduced shortly after the Industrial Revolution, it helped many countries to appreciate the importance of the free market economy, in particular, the private ownership of resources. As such, the "classical economic theory helped countries to migrate from monarch rule to capitalistic democracies with self-regulation." This helped many European countries such as Great

Britain, France, and the United States gain an immediate advantage in the global economy and became the superpowers in World War One (Young, 2020).

As time progressed through the late 19th century and very early 20th century, the Classical Economic Model was modified to the decision-making process of individuals and firms in the economy. As such, the law of demand and supply was established, marking the fundamentals of microeconomics and the beginning of "Neoclassical Economics." Nevertheless, the economists' approach to the macroeconomy in the western world remained relatively the same: in the case of an economic crisis, the invisible forces in an economy would eventually stimulate it back to its potential output. For instance, during the Panic of 1873, also known as the Long Depression, there was minimal government spending and the government adopted a laissez-faire approach towards the economy. This economic crisis came with several bank and railroad failures. The government announced that it would purchase $10 worth of bonds, but they never did, and the high unemployment rate resulted in major labor unrest. The Congress passed a bill in 1874 to print currency to reduce the real value of debts, but President Grant vetoed the bill and campaigned against fiscal policy to correct the economy (Lee, 2008). The economy was eventually able to recover, but it observed several boom and bust cycles in the coming years, which according to classical economists, are natural phenomena. The Panic of 1873 implies that the government expected the Invisible Hand to fix the economy; therefore, it was in their best interest to leave it alone.

The classical economic theory was ultimately challenged by British Economist John Maynard Keynes during the Great Depression. Keynes was a revolutionary economist who influenced new macroeconomic insights that suggest Adam Smith's "Invisible Hand" would not always be effective during a severe economic recession; the economic model was too simple and general to be applied in the many complicated societies. Together, his proposed theories formed Keynesianism, an economic theory that is widely practiced in many economies in the world.

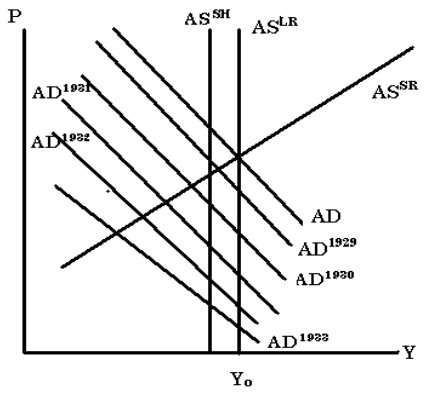

Figure 2: The United States economy can be characterized by a constant leftward shift of aggregate demand during the Great Depression.

In the United States, after the two severe stock market crashes in late 1929 and the failure of over 650 banks, the money supply of the economy was severely reduced, increasing the value of each American Dollar and strictly reducing the amount of loans available for businesses and lenders. As a result, it became costly for businesses lenders to pay back, causing a sharp increase in the national unemployment rate and personal bankruptcies. Over the next few months, consumer confidence decreased throughout the nation, leading to decreased investment in capital and spending on goods and services, shifting aggregate demand to the left as shown in Figure 2. In 1930, the United States began to suffer from the severe Dust Bowl Drought that struck 23 states in the Mid-Atlantic Region, which destroyed many farm fields and cut off the United States' food supply. President Hoover ordered assistance from the American Red Cross, but the drought prolonged and the economy further collapsed. By the end of 1930, the Bank of United States collapsed from a sudden large crowd of withdrawers. The unemployment rate had increased to 8.7% and prices fell by 6.4% (Amadeo, 2020, *Great Depression Timeline*).

At this stage, many major businesses closed down and dismissed a large proportion of its workers. This phenomenon also applied to many other countries such as Brazil, Germany, Great Britain, and France at that time, but the United States began to suffer from the worst of it. According to Figure 2, aggregate demand of the United States

economy had significantly fallen by this time, leading to a decreased price level and output. By February of 1931, many American citizens were laid off and had to rely on soup kitchens to feed themselves, which caused massive food riots in Minneapolis, Minnesota. While President Hoover attempted to resolve the massive economic crisis, he established and signed the Revenue Act of 1932 which increased top income taxes to 63% with the hope to reduce federal deficit and restore business confidence. Much to people's surprise, the Revenue Act of 1932 further counteracted aggregate demand throughout the rest of the year, moving the United States economy into a further recession (from AD1932 to AD1933) with an unemployment rate of 23.6% (Corbett et al., 2014).

Nevertheless, it was at this point that parts of America realized the rate of deflation had slowed down and stabilized, but not the unemployment rate. But according to the classical theory, prices and wages would continue to fall as long as the economy is in a recessionary gap; they would fall until production begins to increase and when consumers regain their purchasing power for consumption and investment. This was clearly not the case in 1933, but the United States continued to shut down banks, increase tax rates, and reduce production with the hope to obtain even lower prices. This caused sustained decreases in aggregate demand, and the United States' economy moved further away from its potential output and was in serious struggle, leading to the termination of President Hoover's responsibilities as a result of the acrid criticisms from the American citizens. Nonetheless, these actions did not further decrease price and wages but rather increased the unemployment rate to 24.9%, leaving the United States' economy in shambles (Pells & Romer, 2020).

Throughout the four years, John Maynard Keynes carefully observed the world economy as it collapsed, confronting whether the Invisible Hand would automatically correct the economy. After inspecting the situation in the United States, Keynes concluded that in some situations, especially in severe recessions where the economy has severely deviated from its potential output, the Invisible Hand is broken. This motivated Keynes to compose his last major book, *The General Theory of Employment, Interest, and Money,* where he concluded that aggregate demand determines the price of labor, not the level of employment. As a result, "potential output" that the classical economists commonly referred to was the result of sustained competitiveness in the economy; in other words, if competition decreases in the economy, the economy would shift and settle on a different new long-run equilibrium. Before publishing his book, Keynes announced that his main objective was to challenge classical economic theory. "I believe myself to be writing a book on economic theory which will largely revolutionize - not I suppose, at once but in the course of the next ten years - the way the world thinks about its economic problems. The difficulty lies, not in the new ideas, but in escaping from the old ones, which ramify, for those brought up as most of us have been, into every corner of our minds" (Keynes, 1936).

Keynes, however, was not entirely opposed to the classical economists. Much like the classical economists, Keynes believed that when the economy is producing beyond or at its potential output, prices and wages are quite flexible: if the economy is experiencing unusually low unemployment and producing beyond its potential, inflation will soon set in, causing immediate upward pressure on prices and wages. and bringing the economy back to its potential. However, as the economy moves into a recessionary gap, prices and wages are no longer flexible and are rather "sticky." Sticky prices and wages indicate that they do not adjust quickly to the current economic situation and in the case of a severe recession, they would stop falling after a certain point. During the Great Depression, people expected that prices and wages would continue to fall to compensate for and counteract the massive levels of unemployment, but they became sticky and stopped falling after the economies entered the severe recession (Kenton, 2018, *What Is the Sticky Wage Theory?*). According to Keynes, the "Sticky Wage Theory" makes sense and could be simply explained with logic. For instance, if the current standard of living requires workers to receive a minimum wage of $10 an hour, workers would only accept to work if they are paid $10 or more. However, if wages have already fallen to $8, workers would not be willing to accept the job

offer, not to mention when wages fall to $4. This scenario explains the high level of unemployment, where nominal wages fell below people's standard of living. As a result, employers were unwilling to pay workers the wage they demanded, and their only solution was to lay off workers to avoid bankruptcy. Therefore, despite the unemployment compensation and programs President Herbert Hoover attempted to enact, the unemployment rate never shrank.

Assuredly, Keynes' "Sticky Wage Theory" allowed for a new formation of the aggregate supply curve. Keynes insisted that the aggregate supply curve would be upsloping in the short run as the law of supply indicates that more goods and services would be supplied at higher price levels. Yet, in the long run, aggregate supply is not as simple as what the classical economists used to believe. For Keynes, the concept of the long run in an economy is much more complicated and uncertain than what most economists previously speculated:"The long run is a misleading guide to current affairs. In the long run we are all dead" (Keynes, 1936).

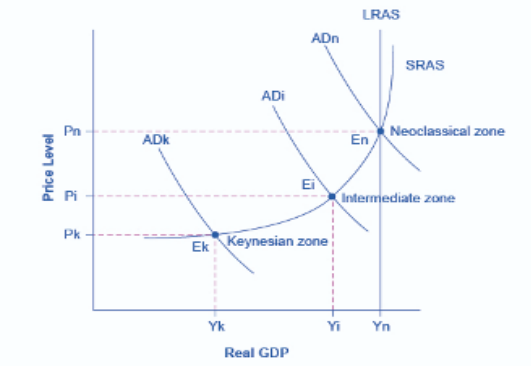

Figure 3: the three parts of the Keynesian aggregate supply curve.

Displayed above, the Keynesian long run aggregate supply curve consists of three ranges: Classical range, intermediary range, and the Keynesian range. The Classical range is in accordance with the classical economists and resembles the economy when it is at its potential or beyond: prices and wages are flexible, so if aggregate demand keeps increasing then the price level would skyrocket while real gross domestic product remains relatively the same. The intermediary range shows an upsloping aggregate supply curve; prices and wages are still somewhat flexible and shifts in aggregate demand from ADn to ADi would change both the economy's output and price level. The Keynesian range, however, was an aspect classical economist could never have predicted; the aggregate supply curve is horizontal, indicating that any changes in an economy's output would not change prices and wages because they became sticky after entering into a recession. As shown in Figure 3 above, the shift of aggregate demand from ADi to ADk results in a very small change in the price level but a large reduction in output, resulting in higher levels of unemployment. Keynes insisted that an economy would be in the intermediary range of the aggregate supply curve once it enters a recession, since the rate at which prices and wages are falling would begin to slow down as aggregate demand continues to fall. In the interim of the Great Depression, the effects of the stock market crash of 1929 moved the United States economy into the intermediary portion of its aggregate supply curve. As conditions worsened in early 1932, the United States economy entered the Keynesian range, where prices and wages stopped falling and remained stagnant while the unemployment rate reached 24%. It was at this time that many people expected prices and wages to fall, so they started saving more and reduced spending on consumption and investment. However, instead of seeing a rightward shift of the short run aggregate supply, the aggregate demand further decreased with a large reduction in output (Willis, 2017). President Hoover's responses and policies did stimulate a rightward shift of aggregate demand to some extent, but their effects were not persuasive enough to bring the United States economy back to the intermediary range of its aggregate supply curve. As a result, the United States economy fluctuated in the Keynesian range until the establishment of Franklin D. Roosevelt's presidency.

If the United States had already moved too far from its previous potential output, what actually ended the Great Depression? In short, President Franklin D. Roosevelt's new economic policies and the arrival of World War II were the main factors that stimulated aggregate demand and brought the United States economy back to the Classical Range of its aggregate supply curve. After achieving a landslide victory against President Hoover in the 1932 presidential election and coming in office on

March 4, 1933, President Roosevelt immediately legislated practicable economic policies in combating the Great Depression. Roosevelt created the New Deal, a series of projects and policies that revolved around the "3 R's": relief of the unemployed, recovery of the economy, and reform of the financial institution.

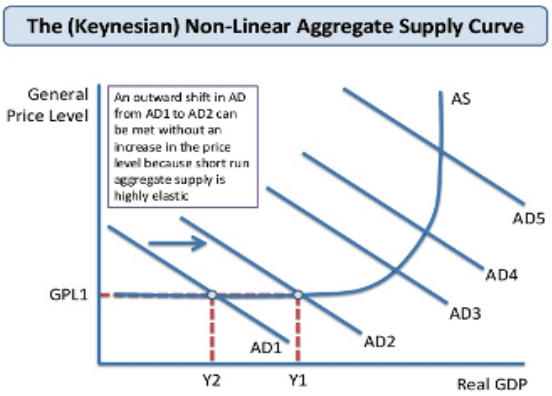

Figure 4: the recovery of the United States economy from AD1 to AD5 observed through the Keynesian Model.

Under Roosevelt's leadership, the United States economy was slow in recovering at first; simply injecting income into the hands of the workers through the Agricultural Adjustment Act and the National Industry Act authorized in early 1935 were not enough to drag the nation out of the depression and aggregate demand remained at AD1 as shown in Figure 4. Nonetheless, President Roosevelt was astute in creating the more aggressive Second New Deal, which enacted the Works Progress Administration and the National Labor Relations Act to offer employment to a large number of the citizens. With the excessive government expenditures on public programs and the unemployment insurance programs, consumers eventually gained purchasing power during when prices and wages were still sticky and static. This stimulated aggregate demand to AD2-as shown in Figure 4-and allowed the United States economy to double its Gross Domestic Product in 1937 from $47 billion to $92 billion (Hardman, 1999). By 1940, the United States' unemployment rate had dropped to 14%; the economy observed an unprecedented rate of job creation, especially the massive job opportunities for women, shifting aggregate demand to AD3 as shown in Figure 4. However, the United States suffered from the devastating attack on Pearl Harbor in December 1941, which prompted the nation to enter World War II. While many anticipated that the economy would enter into another recession from the massive damage, the United States became the major exporter to Great Britain and France; $32.5 billion worth of war goods were exported to the Allied Powers between 1941 to 1945. World War II allowed the United States economy to enter into the intermediary range of its aggregate supply curve (AD4) and through the increased net exports, the economy ultimately returned to its potential output (AD5) in 1943, when prices and wages were flexible again (Willis, 2017). Altogether, President Roosevelt's New Deal Programs and the onset of World War II allowed for sharp increases in aggregate demand, bringing the United States out of the Great Depression.

Clearly, Roosevelt's policies were exactly in accordance with Keynes' solutions to economic recessions: to advocate for and conduct expansionary fiscal and monetary policies when the economy failed to correct itself. Expansionary fiscal policy encourages government spending and lowers income tax rates and expansionary monetary policy increases the nation's money supply, which in turn lowers the interest rate and encourages interest-sensitive consumption and investment. Both of these policies are the most essential factors in lifting aggregate demand, which in turn substantially reduces the unemployment rate. In *The General Theory of Employment, Interest, and Money,* Keynes campaigned for job creation ideas such as "the government should pay people to dig holes in the ground and then fill them up," since "it doesn't matter what [people] do as long as the government is creating jobs." (Keynes, 1936) Although this seems ridiculous, Keynes was trying to emphasize the importance of government spending and the fact that only the government would be willing to spend during a recession. Keynes' innovative analysis of the new macroeconomic policies reminded the world that government and federal reserve interventions are absolutely necessary when an economy is facing sustained problems. Unfortunately, the economy does not always follow the basic foundation of the Invisible Hand; Keynes'

effort in ratifying the role of the government and federal reserve in the economy has brought many long-lasting impacts and transformed the ways economists view severe recessions in the modern world. As such, Keynes reminded the American population that: "If you owe your bank a hundred pounds, you have a problem. But if you owe a million, it has" (Keynes, 1936).

3. Phillips Curve

Although Keynesianism generally favors any sort of interventions to control the economy under devastating circumstances, Keynes was more of a direct supporter of fiscal policy over monetary policy. Keynes believed that fiscal policy, especially controlling government expenditures, has a direct influence on aggregate demand. Monetary policy, on the other hand, only changes the money supply and the interest rate at first, which would then influence consumer decisions and eventually change aggregate demand. This process, according to Keynes, takes a significant amount of time, shatters the confidence of many investors, and leaves no difference when the interest rate is already low. This "Liquidity Trap Phenomenon" was evidenced again in the Great Depression: increased savings, low investment confidence, and low interest rates as a result of the stock market crashes of 1929 did not prompt the American population to engage in capital investment. Fiscal policy, on the other hand, has nothing to do with individual decision-making and thus proved to be effective in the Great Depression.

Figure 5: The Phillips Curve illustrates that there is a tradeoff between inflation and unemployment.

It is often burdensome in determining which policy is more effective over the other and many economists today have conceded that implementing a combination of both would often maximize the benefits provided to the economy. After the events of World War II, many economists rejected the classical theory and became avid supporters of Keynesianism. Building on his theory, British economist William Phillips advanced a new economic model known as the Phillips Curve in the late 1950's through his book *The Relation between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom*. The Phillips Curve, shown above in Figure 5, can be conceptualized in that there exists a negative correlation between inflation and unemployment in the short run. For instance, if the economy moves from point A to point B, it will observe a 3% increase in unemployment but a 3% decrease in inflation. This phenomenon was clearly shown in the Great Depression when high levels of unemployment were accompanied by deflation of prices and wages.

Nonetheless, as time progressed to the early 1970s, the United States suddenly began observing unprecedented levels of inflation, reaching double digits by 1974 and levels as high as 13.5% in 1980. According to the classical economic theory, an economy would be experiencing high levels of inflation if it is producing beyond its potential output, indicating that the economy must be doing exceptionally well and experiencing long run economic growth. However, this was not exactly the case in the United States; rather, the economy suffered from cost push inflation - constant leftward shift of the short run aggregate supply curve largely due to increases in oil prices. At this time, supporters of Keynes and Phillips supposed that the economy would be experiencing lower levels of unemployment under high levels of inflation, but this was again, not the case, and the national unemployment rate rose to 8.5% in 1975 and a stunning 9.7% in 1982, during times when inflation was also high (Nielson, 2020, *Stagflation in the 1970s*). This severe stagflation phenomenon could no longer be explained by William Phillips' theory, and the United States found itself in another economic crisis. Like the Great Depression, this

crisis has led to another reevaluation of macroeconomic policy.

4. Monetarism

As the United States experienced "The Great Inflation" of the 1970's, American Economist Milton Friedman rose to prominence with his theory that supports controlling the nation's money supply to reduce inflation. Monetarism is often recognized as utilizing monetary policy, that is, the Federal Reserve's actions of controlling the growth rate of the money supply to regulate the economy. Collaborating with Anna Schwartz in 1963, Friedman composed his book *A Monetary History of the United States, 1867-1960,* in which he argued that "the central bank of the world's economically most important nation in 1929 was essentially leaderless and lacking in expertise" (Friedman & Schwartz, 1963), challenging Keynes' believe that the main cause of the Great Depression was a lack of government spending. Friedman believed that the Federal Reserve had much a greater influence on the United States economy than what was previously thought: the misguided target growth rate of the money supply resulted in markets behaving erratically, causing the sudden stock market crash in 1929.

$$MV = PY$$

Equation 1: The Quantity Theory of Money (Irving Fisher Equation)

Monetarism is founded by the Quantity Theory of Money (shown in Equation 1), an equation established by classical economist Irving Fisher in the 1920s that shows that an economy's "money supply multiplied by velocity (the rate at which money changes hands) equals nominal expenditures in the economy (the number of goods and services sold multiplied by the average price paid for them)" (Jahan & Papageorgiou, 2014).

The classical economists argued through the Say's Law that in the long run, the velocity of money and the total output in the economy would remain relatively static; the economy would produce at its potential output while maintaining a stagnant flow of money. This suggests that increasing the money supply will only result in a proportional increase in the price level, leading to severe levels of inflation instead of steady economic growth. Friedman was able to use the Quantity Theory of Money to criticize the validity of the Phillips Curve in 1968: in the long run, the Phillips Curve is not an accurate reflection of the economy as there seems to be no relationship between inflation and unemployment.

Moreover, Friedman used the Quantity Theory of Money to argue against Keynes' fiscal policy and his statement that "money does not matter." The Keynesians accentuate the efficacy of the "multiplier effect" when fiscal policy is used. The multiplier effect suggests that initial government expenditure results in "increases in private spending that additionally stimulates the economy" since these expenditures would go directly to the incomes of the consumers (Silver, Kagan & Frankenfield, 2020).

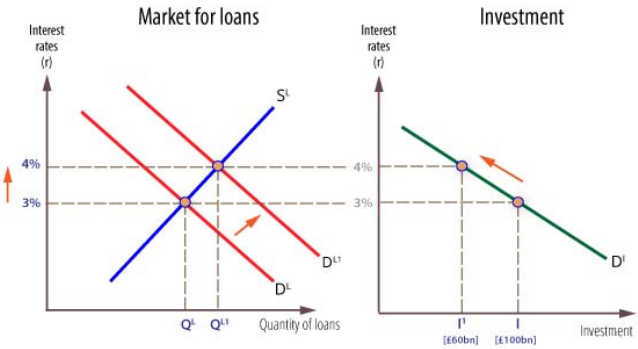

Figure 6: Government borrowing increases the demand for loanable funds and thus the interest rate, causing a reduction in the quantity of desired investment, depicting the crowding out effect.

However, Friedman and the Monetarists were not assured that the multiplier effect is the only consequence of fiscal policy. Essentially, Keynes had somewhat neglected the importance of interest rate to the economy, and most importantly, the consequences of deficit spending by the government. During times of severe economic conditions, governments cannot rely on tax revenues to facilitate their intentions of spending. As a result, governments play a key role in borrowing from the available supply of loanable funds from the private sector to undergo severe deficit spending to

stimulate aggregate demand. According to the classical economic theory, the amount of loans in an economy is the sole determinant of interest rate. Consistent borrowing from the government would increase the demand for loanable funds, shown in Figure 7 above. As the government's demand for loans increases, less loans will be available to individuals, aggrandizing the interest rate and decreasing the amount of desired investment (I to I'). This is a reflection of the "crowding out effect," in which the increased interest rate from government borrowing makes it burdensome for individuals to commit to capital investment and consumption (Silver et al., 2020). This phenomenon would counteract the effects of government spending, since government spending may occur simultaneously with reductions in investment spending.

As Keynesianism fell out of popularity with policymakers, the United States economy was left stranded and it was entirely up to the monetarists to resolve the effects of stagflation. As a contractionary monetary policy is mainly used to control the rate of inflation, the monetarists realized that to stabilize the economy, inflation should be first controlled, even if "it temporarily causes a disruption to economic activity and, for a time, a higher rate of joblessness." If we never get rid of the problem of inflation, prices and wages will continue to rise, causing inevitable rises in the unemployment rate. In 1979, Paul A. Volcker took over as the chair of the Federal Reserve Board, where he enacted policies in favor of monetarism to the unprecedented levels of inflation. Through Volcker's efforts, the Monetary Control Act of 1980 was established (Bryan, 2013). By this time, the United States' policymakers and economists have clearly shown preference for monetarism. When President Ronald Reagan took office in the same year, his economic ideologies were consistently in accordance with the monetarists. Reagan supported cutting spending and taxes while tightening the money supply to reduce inflation. During the early stages of his presidency, president Reagan put forth the Economic Recovery Tax Act of 1981, which significantly lowered nationwide income tax rates and the top marginal tax bracket by 20% (The Ronald Reagan Presidential Foundation and Institute, 2000). Through Volcker's and Reagan's achievements, the United States economy began to observe recovery. Although lending activities fell to its lowest, the economic policies enacted to reduce inflation were successful. The United States was able to obtain an inflation rate of 3.21% in early 1983. "The Great Inflation" ended and the United States economy was able to leave the recessionary gap in late 1982 (Bryan, 2013).

Assuredly, Friedman's emphasis on monetary policy opened new doors in the history of macroeconomic theory. Economists have come to the full understanding that a commitment to price stability is essential for maximizing employment while attaining stable economic growth. From the stagflation crisis, a new and improved economic thought emerged that provided the theoretical underpinnings of Friedman's theory of the long run Phillips Curve. Robert Lucas Jr. is an American economist at the University of Chicago who won the Nobel Prize in Economics in 1995 for his new contributions to the rational expectations theory. In short, the already developed rational expectations theory suggests that individuals' current perceptions of the economy would very much influence their future economic decisions. While this theory emerged from Keynes as early as the 1930s, nothing about it was particularly inspiring and the theory did not progress farther until Lucas' contribution. In a paper written in 1972, Lucas argued that if individuals are rational and regularly predict future economic factors such as inflation, they will unintentionally adjust their price and wages to accommodate their future expectations. As a result, people would be able to predict the Federal Reserve's actions and their impacts, unless the Federal Reserve conducts some sort of unparticipating or surprising change that contradicts or interferes with the people's expectations. Through the use of mathematical models, Lucas explained that if central banks consistently print money to take advantage of the Phillips Curve to stabilize the economy, individuals will soon anticipate the Federal Reserve's actions and adjust their labor supply accordingly. As a result, the negative relationship between inflation and unemployment disappears, even in the short run, leaving both the short run and long run Phillips Curve to be vertical (Chappelow, 2020).

Lucas' theory provided explanation for why the United States economy was observing stagflation in the 1970s, where both inflation and unemployment were high. His theory also strengthens Friedman's argument that the negative relation between inflation and unemployment was not as strong as what William Phillips has hypothesized; the curve could be vertical after all. Having added new value to modern macroeconomic theories, Lucas successfully developed the New Classical school of economic theory and the Lucas Critique, which implies that some past macroeconomic data are unreliable in economic policymaking because individuals would unintentionally make rational decisions to alter the state of the economy (Chappelow, 2020). After winning the Nobel Prize, Lucas was championed by many economists as he further proved that the economy should rely on the Federal Reserve for policies as individuals can easily predict its actions. All in all, Lucas claims in 2003 that "the central problem of depression prevention has been solved for all practical purposes, and has in fact been solved for many decades." (Lucas, 2003)

But after all these years, monetarism still has its own drawbacks, and the attempt to discard Keynesianism throughout the late 20th century eventually proved to be problematic. As time progressed to the 2000s, the United States economy encountered its most recent major economic meltdown: The Great Recession of 2008. This major recession followed after the 2006 Subprime Mortgage Crisis. In the early 2000s, the United States economy was facing stable economic growth and low interest rates. These low interest rates allowed people who would normally never have been able to purchase a home to become homeowners. As a result, housing prices rose drastically from the rising demand of borrowers. To compensate for the rise in demand, the Federal Reserve kept interest rates low and did not adjust the money supply This was a tremendous risk, since the low interest rate allowed lenders to approve lending to subprime borrowers or those who lacked creditworthiness. The mortgage brokers then took advantage of the low interest rates and the constant demand for loans. (Amadeo, 2020, *The Great Recession of 2008*).

The Bush Administration and the Federal Reserve believed that the over reliance on derivatives was not a problem as long as money supply is growing consistently with low interest rates. While the Federal Reserve ignored potential warnings from the Commerce Department in late 2006 about declining housing permits, many speculative investors had already stopped giving out loans due to the high risk. This caused housing prices to suddenly decrease, crashing the housing market and increasing the amount of foreclosures. In April of 2007, the Federal Reserve attempted to resolve its over reliance on derivatives through encouraging lenders to make loan arrangements (Nielson, 2020, *Why Housing Market Bubbles Pop*). However, this was not enough to conquer the Subprime Mortgage Crisis, and the housing crisis soon created a Domino Effect that affected the entire economy.

The situation quickly worsened and somewhat modeled the Great Depression in that many borrowers struggled to pay back to lenders. As predicted, the stock market finally crashed on September 29, 2008, shifting the United States economy into a major recessionary gap. The Federal Reserve took the partial blame for this economic crisis; it overlooked many warnings from investors and underestimated the high risks associated with mortgages. Luckily, the government responded quicker to this recession than it did in the early 1930s. On October 3, 2008, the Congress authorized the Troubled Asset Relief Program (TARP), a $700 billion support from the federal government that aimed to inject capital into many of the failing banks. Moreover, newly elected President Barack Obama established a $787 billion economic stimulus to recover the economy; $282 billion served as tax cuts and $505 billion were government expenditures that assembled new healthcare systems, education, and projects. Eventually, this major stimulus helped to end the Great Recession of 2008 (Amadeo, 2020, *The Great Recession of 2008*). However, the unemployment rate at first lingered around 10%. As the majority of the congress was still Republican at this time, many believed that fiscal measures should not be too tight and continued to advocate for austerity measures. These counteractive measures slowed the rate of economic

recovery despite TARP and policies of the Obama administration already put forth. Luckily, President Obama resolved the economic crisis with a different mentality (Bivens, 2016). In January of 2009, Obama declared that "if we don't act swiftly and quickly we could see a much deeper economic downturn that could lead to double-digit unemployment." This shows that the Obama administration approached the economy with Keynesian influences, much similar to Roosevelt's New Deal Programs during the Great Depression. With these fiscal incentives, the United States was able to end the Great Recession in June of 2009.

The Great Recession of 2008 manifested the fragility of the monetary system and the poor decision-making of the Republican members of the congress. Monetary policy failed to predict the consequences of excessive lending, not to mention the Federal Reserve's lack of response to control the money supply and federal funds rate during the peak of this recession. The Great Recession of 2008 was profound in that it proved to economists that Keynesianism is still relevant and should not be abandoned altogether. Undoubtedly, Friedman's arguments on Monetarism are applicable to many situations, but the United States would not have gotten out of the recession if the government did not implement the two stages of expansionary fiscal policy. Ultimately, the Keynesian approach resolved the nation's second most significant economic crisis, once again proving that fiscal policy has more of a direct influence on aggregate demand.

The two major economic downturns in America's history have convinced policymakers that Keynesian practices are still very much relevant. After all, expansionary monetary policy has its own limits in that it fails to prevent deflationary spirals. This phenomenon occurs when the Federal Reserve already sets nominal interest rate close to 0%, but this effect is not enough to promote increases in consumption, borrowing, and investment. As a result, the output and price level would continue to fall even if the nominal interest rate is no longer apparent in the economy. In the case of a tragedy like this, government spending would then be the only incentive to increase aggregate demand (Kagan, 2020). In a recent study from *The Journal of Economic Education*, Buttet and Roy (2014) argued that when the nominal interest rate "cannot be reduced any further, any decline in inflation means an increase in the real interest rate which in turn reduces aggregate demand and output." They used several mathematical models and derivations to show that an economy could settle at a new equilibrium when the nominal interest rate becomes close to zero. This new equilibrium is at a severe risk of falling into a deflationary spiral if any negative shocks were to occur in the economy. This study is essential in that the Federal Reserve has kept the nominal interest rate close to zero in 2008, which could provide insights on how the housing crisis significantly affected the whole economy. Buttet and Roy (2014) concluded by suggesting fiscal stimulus is more effective to bring an economy out of a deflationary spiral.

5. Conclusion

The evolution of modern macroeconomic theories has transformed our understanding of how policymakers manage the economy during times of economic crises. From the works of economists John Maynard Keynes, William Phillips, Milton Friedman, and Robert Lucas Jr., we can conclude that it is no longer valid to trust the Invisible Hand under harsh economic conditions. The classical economists severely underestimated the scope of the Great Depression and established models that were too simple to be explained in the complicated world. Although the debate between whether we should follow Keynesianism or Monetarism is still prevalent, it is without doubt that both economic theories have their strengths and drawbacks.

Keynesianism and the enactment of fiscal policy have been successful during major economic recessions; as consumer confidence falls to its lowest, the liquidity trap dilemma arises. Even if interest rates are lowered, the public would still prefer to hold cash rather than to hold debt since investment is risky during economic downturns. Therefore, fiscal spending is the only solution to stimulate aggregate demand and to stop the deflationary spiral when interest rates could not be lowered more. Fiscal policy, however, has proven ineffective in circumstances in which government deficit spending causes the Crowding Out Effect,

which would counteract the intended effects of fiscal policy. On the other hand, monetarism and the actions taken by the Federal Reserve were effective during times of great inflation and slow economic growth. Managing the money supply is crucial; the Federal Reserve's actions to target interest rates and change the federal funds rate have resulted in price stability and reductions in inflation. Moreover, the Stagflation of the 1970s have taught the Federal Reserve the lesson of not repeating the mistakes it made during the Great Depression. The Federal Reserve has taken advice from Milton Friedman in promoting steady growth of the money supply to control inflation and providing more liquidity to banks to avoid major negative money supply shocks.

Ultimately, the central problem in modern macroeconomy is not whether one policy is superior over the other. The implementation of both fiscal and monetary policy is regularly observed during short run business cycle fluctuations in the economy and are crucial for future economic growth. The most important thing for policymakers is to know when to use each policy and not to wholly favor one over the other. If policymakers are able to make the right decision and predict outcomes that would cause the least harm to the vast majority, then we would be able to prevent catastrophes like the Great Depression from happening again.

No one knows for sure what lies in the future for the macroeconomic world. But one thing is certain: we can no longer rely on the classical economic model and expect prices and wages to always adjust to current economic circumstances. We should continue to advocate for active fiscal and monetary policies during times of economic hardships to prevent future economic crises. As the old saying from President Theodore Roosevelt suggests, "in any moment of decision, the best thing you can do is the right thing, the next best thing is the wrong thing, and the worst thing you can do is nothing."

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Factors Affecting One's Willingness to Decrease Their Carbon Footprint

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Abstract

To gain a better understanding of what factors generally make a person more willing to help their environment, a study was conducted with nationally representative publicly available survey data from the United States to determine if age, gender, and belief in climate change affect a person's willingness to reduce their carbon footprint. Odds ratios (ORs) and the associated 95% confidence intervals (CIs) were used as the measure of association and analysis was first conducted by grouping undecided participants (i.e., having a neutral response to a Likert scale question) with those who are willing to reduce their carbon footprint. It was discovered that believing in climate change is a significant risk factor for willingness to reduce carbon footprint (OR: 6.88, 95% CI: 4.37-10.81). Males were significantly less likely to be willing to reduce carbon footprint compared to females (OR: 0.47, 95% CI:0.32-0.68). Age, classified into millennials versus older, did not affect willingness to reduce a carbon footprint (OR: 1.50, 95% CI: 0.96-2.34). Analyses were repeated after regrouping the participants who were neutral with those who were unwilling to reduce their carbon footprint, but this did not affect the study conclusions. These findings will help determine which demographics need to be targeted with information about climate change and its negative effects as well as aid others carrying out similar types of studies with a neutral response category included.

Keywords: survey, carbon footprint, climate change, gender, millennials, neutral response

1. Introduction

Not everyone believes in the existence of climate change, but the many who do would describe it as the rise in the temperature of the earth's atmosphere due to an increase in carbon dioxide emissions, mainly at the hand of humans (BBC News, 2020 May 5). If people don't believe in climate change and its consequences, they will be unlikely to take action against it and its ramifications. According to scientists, climate change has drastically negative effects on the environment; increasing worldwide temperatures, causing a rise in ocean levels, creating natural disasters, harming wildlife, and much more (National Oceanic and Atmospheric Administration, n.d.). Many politicians have urged those in power and the public to take action against climate change and global warming. Perhaps most importantly, because climate change is thought mainly to be caused by carbon dioxide emissions, people are encouraged to reduce their carbon footprint. It is believed that the daily life of the average individual, and more specifically the carbon footprint they leave behind, plays a pivotal role in the condition of our

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environment. A carbon footprint is the amount of carbon dioxide that one produces in their everyday lives (Selin, n.d.). Carbon dioxide is emitted when we drive, use energy in our homes, and even when the food we eat is produced. There are many ways in which individuals can combat this crisis, such as limiting their use of plastic, using more energy efficient cars, carpooling or using alternative modes of transportation, and being more energy-conscious when using home appliances. Whether or not these changes occur depends on how willing a person is to change their lifestyle to better the environment. To this end, the primary objective of this research was to use publicly available nationally representative survey data for the continental United States to investigate the factors that may affect whether a person is willing to reduce their carbon footprint. To do this, the factors of gender, age, and whether or not one believes in climate change were evaluated. We hypothesized that being a millennial and believing in climate change would make a person more likely to be willing to reduce their carbon footprint while gender would have no effect.

Surveys commonly use Likert scale questions where respondents are asked to indicate their level of agreement with a given statement by way of an ordinal scale (Mcleod, 1970). The Likert scale questions often have an odd number of responses with an equal number of positively- and negatively-worded responses and a neutral or undecided response option. For example, a 5-point Likert scale for willingness would be: very unwilling, unwilling, neutral, willing and very willing. However, questions on the Likert scale with an odd number of responses are often simplified into binary variables for simplicity of analysis and interpretation, whereby the neutral or undecided responses either have to be (i) dropped from analysis or (ii) grouped with the positively- or negatively-worded responses. The former approach can lead to a considerable loss of data because of which the latter approach is typically favored. However, this raises the question whether grouping of the neutral responses with positively- vs. negatively-worded responses would lead to different conclusions. Therefore, the secondary objective of this study was to determine whether the conclusions resulting from the primary objective would change depending on how neutral responses are treated.

2. Methods

For this study, the 2015 Cornell National Social Survey (CNSS) was used as a data source (Survey Research Institute, 2015). CNSS uses random digit dialing in order to obtain telephone survey responses from 1,000 adults, defined as people age 18 and older, from the continental United States each year (around 14,000 people are initially contacted to get 1,000 valid responses). Within this survey, each individual is asked a variety of questions, ranging from their age and yearly household income to their stance on various political issues. This data set was chosen as it is fairly recent and contains many topics of interest for this study, mainly perceptions about climate change and people's stances on helping their environment. The survey was conducted with approval of Cornell University's Institutional Review Board (protocol #1402004459).

Table 1 shows questions from the 2015 CNSS, in their original format with the associated question codes that were used in this study. The outcome of interest within this investigation was a person's willingness to reduce their carbon footprint (PMq1) (Table 1). We wanted to see if a person's age (YOB_R), gender, and whether or not they believe in climate change (SBAq3) affected this outcome (Table 1). In order to test this, each of the three risk factors (age, gender, and belief in climate change) was evaluated separately with respect to the outcome of interest to see if the two were associated, meaning that the considered factor is a risk factor for willingness to reduce carbon footprint. In order to simplify the assessment process, each of the questions was reformatted into a binary variable, meaning that responses from the original question were grouped into two categories. In the 2015 CNSS dataset, the possible responses for the outcome of interest were 'very unwilling', 'unwilling', 'somewhat unwilling' (these three were classified as "unwilling") and 'very willing', 'willing', 'somewhat willing' (these three were classified as "willing"); responses 'refused- don't believe in/understand climate change' and 'do not know' were omitted from analysis. There was also a 'neutral' category in the carbon footprint outcome. The calculations for

the study were carried out twice; first with the neutrals grouped with the 'willing' category, and subsequently with them grouped with the 'unwilling' category to see if this would affect the conclusions. In the survey, the participants' self-reported age was recorded with an integer. However, our interest was in determining whether being a millennial is associated with the outcome of interest. Therefore, for the factor of age, anyone born during or after 1981 was classified as a 'millennial', while those born before 1981 were classified as 'older'. The survey question about belief in climate change had four possible responses: 'yes', 'no', 'don't know', and 'refused'. The 'yes' and 'no' categories were kept as 'believe' and 'not believe', respectively in the categorization, while the 'don't know' response was omitted (none of the survey participants refused to respond). Finally, the considered risk factor of gender was already split into two categories, 'male' and 'female' and was used as such in analysis. Any person with an omitted response for any of the considered factors was taken out of the study entirely.

Table 1. Questions and frequency of responses in the 2015 Cornell National Social Survey used in analysis with age not included in the table due to the integer nature of the responses

Question (code)	Response	Number	Percent
How willing are you to change your current lifestyle in order to reduce your carbon footprint? (PMq1)	Very unwilling	77	7.7%
	Unwilling	40	4.0%
	Somewhat unwilling	40	4.0%
	Neutral	136	13.6%
	Somewhat willing	235	23.5%
	Willing	188	18.8%
	Very willing	273	27.3%
	Refused- don't believe in/understand climate change	5	0.5%
	Do not know	4	0.4%
	Refused	2	0.2%
Climate change refers to major changes in weather, such as shifts in temperature, precipitation, or wind patterns, and increasing incidence of extreme weather that occur over several decades or longer. Do you believe that climate change is happening? (SBAq3)	Yes	820	82.0%
	No	100	10.0%
	Don't know	80	8.0%
Gender (gender)	Male	501	50.1%
	Female	499	49.9%

Each of the potential risk factors: age, belief in climate change, and gender, were placed in a 2 x 2 table with the outcome, willingness to reduce carbon footprint, to see if there was an association between

any of the potential risk factors and the outcome of interest. Each table had the potential risk factor in the left column, with the two different categories listed for each (i.e., 'believe'/'not believe' in climate change, 'millennial'/'older', and 'male'/'female'). On the top right of each table was the outcome of interest, labelled "willing" or "unwilling" to reduce carbon footprint. An example of a 2x2 table for cross-tabulation of a factor and the outcome of interest is shown in Figure 1.

	Willing	Unwilling
Believe	a	b
Not believe	c	d

Figure 1. Illustration of a 2x2 table for the outcome willingness to reduce carbon footprint and the climate change risk factor as an example

Then, for each factor the number of people categorized into each of the four factor and outcome combinations (corresponding to cells a, b, c and d in Figure 1) was counted and entered into a 2x2 table. With these tables, the odds ratios (ORs) were calculated. This was achieved by first finding the odds of each factor with respect to the outcome, e.g., odds of believing in climate change in those who are willing to reduce their carbon footprint (a/c in Figure 1) and odds of believing in climate change in those who are unwilling (b/d in Figure 1). To calculate the OR, the two odds were divided (odds of believing in climate change in those who are willing divided by odds of believing in climate change in those who are unwilling). An OR of 1 means that there is no association between the factor and outcome because the two odds are the same. The farther the OR is from 1, the stronger the association. An OR larger than 1 indicates positive association while an OR below 1 indicates negative association. To determine whether the estimated OR is statistically significantly different from the value of 1 we estimated the corresponding 95% confidence interval (CI) using the large sample normal approximation (LSNA) method with variance based on a Taylor series expansion. It is known that OR does not follow a normal distribution, but the natural log (ln) of OR (ln(OR)) is approximately normally distributed when numbers a, b, c and d in 2x2 tables are relatively large (at least 5 as a rule of thumb), and thus ln(OR) is used to calculate the corresponding CI in the LSNA method (Morris and Gardner, 1988). Since our sample size met the sample requirement for application of the LSNA method, the error factor (EF)and from that the lower and upper limits of the OR's 95% CI were calculated for each factor using the following equations (Giesecke, 2002):

$$\text{Error factor} = e^{1.96\sqrt{1/a+1/b+1/c+1/d}} \quad \text{Eq. 1}$$

where a, b, c and d are defined as in the example in Figure 1, and $\sqrt{1/a + 1/b + 1/c + 1/d}$ is the standard error of ln(OR).

$$\text{Lower limit of the 95\% CI} = OR/\textit{error factor} \quad \text{Eq. 2}$$

$$\text{Upper limit of the 95\% CI} = OR \times \textit{error factor} \quad \text{Eq. 3}$$

The estimated 95% CI indicates whether the corresponding OR is statistically significantly different from one. This is because the 95% CI corresponds to statistical testing with a p-value of 5%. That is, if the 95% CI includes the value of one it means that the factor is not statistically significantly associated with the outcome whereas if it does not include the value of one the factor is associated with the outcome.

The calculation process was undergone twice as for the first calculations the neutrals in the willingness to reduce carbon footprint outcome were counted as "willing" while in the second calculations we counted them as "unwilling" because they could not be reasoned into either category and omitting them completely would cause the amount of data to decrease considerably. The estimated ORs and 95% CIs were compared between the two approaches of treating neutral responses in analysis to determine whether they would lead to different conclusions about the evaluated risk factors. To compare the results of two approaches visually, we used a bar graph, where the OR values were natural log transformed to improve visual assessment of ORs smaller than one. All analyses were conducted on Google sheets.

3. Results

Out of the original 1,000 participants in this study, 95 of them were omitted from the analysis due to missing information, resulting in 905 individuals' data to use for the study. When we included the neutrals in the 'willing' category for willingness to reduce carbon footprint, 767 people (84.8%) stated they were willing to reduce their carbon footprint ('willing') while only 138 people (15.2%) were 'unwilling' (Table 2). Moving the neutrals into the 'unwilling' category changed the frequencies: 654 people (72.3%) were classified as 'willing", while 251 people (27.7%) were classified as 'unwilling' (Table 2). In the study, out of the 905 individuals, 807 (89.2%) said that they believed in climate change while 98 (10.8%) said they did not (Table 2).

Table 2. Response statistics for the binary variables representing the outcome of interest, willingness to reduce carbon footprint, and the considered risk factors (gender, age, and belief in climate change). The outcome is shown separately with neutrals grouped with the 'willing' and 'unwilling' category

Variables and associated levels	Number	Percent
Willingness to reduce carbon footprint (*neutrals grouped with 'willing'*)		
Willing	767	84.80%
Unwilling	138	15.20%
Willingness to reduce carbon footprint (*neutrals grouped with 'unwilling'*)		
Willing	654	72.30%
Unwilling	251	27.70%
Believe in Climate Change		
Believe	807	89.20%
Not believe	98	10.80%
Age		
Millennial	240	26.50%
Older	665	73.50%
Gender		
Male	455	50.30%
Female	450	49.70%

The age of participants in this study ranged from 18 to 96 years old (being born between 1997 and 1929, respectively), with the average age of 48.9 years old (standard deviation 18 years). After categorization of participant ages, it was found that 240 (26.5%) of the individuals were millennials while 665 (73.5%) were older (Table 2). In terms of gender, 455 (50.3%) of the participants included in the analysis were male and 450 (49.7%) were female (Table 2).

Through the statistical analysis, a strong positive association was found between willingness to reduce carbon footprint and believing in climate change both

when neutrals were in the 'willing' category for the outcome and when they were in the 'unwilling' category (Figure 2). When neutrals were in the 'willing' category the OR was 6.88 with a 95% CI of 4.37-10.81 (EF=1.57; Table 3). When the neutrals were included in the 'unwilling' category, the OR was 6.93 and the 95% CI was 4.41-10.91 (EF=1.57; Table 4). Since both of the ORs and their associated 95% CIs were well over 1, it can be concluded that there is a strong positive association between believing in climate change and willingness to reduce carbon footprint. In other words, believing in climate change is a risk factor for being willing to reduce carbon footprint. As can be seen, putting the neutrals into different categories did not have an effect on that conclusion (Figure 2).

When a statistical analysis was done between willingness to reduce carbon footprint, with the neutrals as 'willing', and age, there was no association found. Although the OR was over 1 (1.50), 1 was included in the 95% CI 0.96-2.34 (EF=1.56) which means that there is no association between the outcome and age (Table 3). Similarly, when the neutrals were in the 'unwilling' category for the outcome, the OR was 1.08 and the 95% CI was 0.77-1.50 (EF=1.39; Table 4). Since the 95% CI includes 1, there is no association between this factor and the outcome of interest. Thus, being a millennial versus older does not play a role in how willing one is to reduce their carbon footprint and the approach to grouping of the neutrals again does not have an effect on this conclusion (Figure 2).

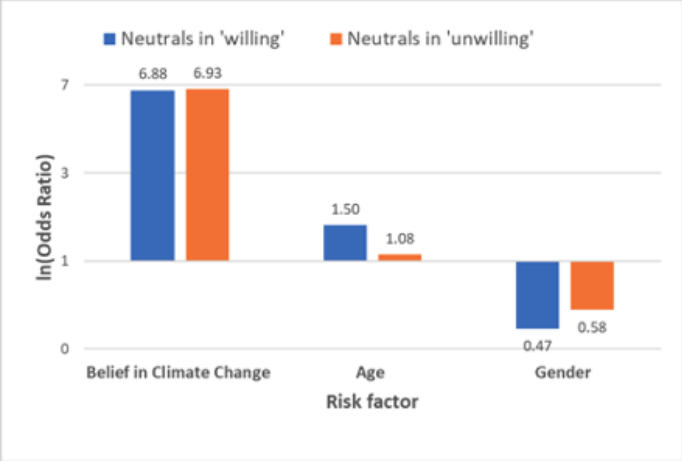

Figure 2. Natural log transformed odds ratios between the considered risk factors (belief in climate change, age, and gender) and willingness to reduce carbon footprint with neutrals grouped in the 'willing' (blue bars) or 'unwilling' (orange bars) category of the outcome variable

Table 3. Cross-tabulation, Odds Ratios, 95% Confidence Intervals and Error Factors between the considered risk factors (belief in climate change, age, and gender) and the outcome of willingness to reduce carbon footprint ('Willing' vs 'Unwilling') when neutrals were grouped with the 'Willing' category of the outcome

Sample Size = 905 Factors	Response	Willing	Unwilling	Odds Ratio	95% Confidence Interval	Error Factor
Belief in Climate Change	Believe	715	92	6.88	4.37-10.81	1.57
	Not believe	52	46	ref*		
Age	Millennial	212	28	1.50	0.96-2.34	1.56
	Older	555	110	ref		
Gender	Male	364	91	0.47	0.32-0.68	1.46
	Female	403	47	ref		

*ref: reference category in calculation of odds ratio

Table 4. Cross-tabulation, Odds Ratios, 95% Confidence Intervals and Error Factors between the considered risk factors (belief in climate change, age, and gender) and the outcome willingness to reduce carbon footprint ('Willing' vs 'Unwilling') when neutrals were grouped with the 'Unwilling' category of the outcome

Sample Size = 905 Factors	Response	Willing	Unwilling	Odds Ratio	95% Confidence Interval	Error Factor
Belief in Climate Change	Believe	622	185	6.93	4.41-10.91	1.57
	Not believe	32	66	ref*		
Age	Millennial	176	64	1.08	0.77-1.50	1.39
	Older	478	187	ref		
Gender	Male	304	151	0.58	0.43-0.77	1.34
	Female	350	100	ref		

*ref: reference category in calculation of odds ratio

4. Discussion

In this study we used publicly available survey data to determine whether certain factors; specifically, age, gender, and whether or not one believes in climate change affect a person's willingness to decrease their carbon footprint. Our findings indicate that gender and whether or not one believes in climate change do affect willingness to reduce carbon footprint while age does not. While the data used in this study have been analyzed before (Dickinson et al., 2016) the current study presents two novel aspects in terms of specifically evaluating the effect of being a millennial on willingness to reduce carbon footprint and the effect of grouping of neutral (undecided) responses in the Likert scale on the results. These findings and novel aspects are discussed in the following paragraphs.

The principle finding of this investigation is that belief in climate change is a significant risk factor for willingness to reduce carbon footprint. That is, those who believe in climate change are likely to also be willing to reduce their carbon footprint. This was hypothesized and intuitively makes sense because if someone believes in climate change, they're likely to understand that it poses negative effects on the environment that need to be combated. A study by Heath and Gifford (2006) found similar results, explaining a connection between people not believing in climate change and greater environmental apathy (along with other risk factors and outcomes that were outside the scope of the current study). These results are important as they suggest that one main reason why people don't take action against the issues facing our environment is because they do not believe in climate change, demonstrating the need to further educate people on the topic. The investigation shows that educating people about climate change and its effects could be vital for getting more people involved in helping the planet and combating the negative effects of climate change. Researchers, as well as those in power, need to look more closely into why people don't believe in climate change, whether it is lack of education on the subject, ignorance, faulty information, etc. and work to get more people to understand climate change and its consequences. Therefore, more research in this area is needed.

Another significant finding of this study was a moderate negative association between being male and willingness to reduce carbon footprint. In other words, females were moderately more likely to be willing to reduce their carbon footprint. A recent study undergone by Pearson et al. (2017) came to a similar conclusion, explaining that females in the

United States tended to show more concern for the environment and saw climate change as a greater issue than males. This greater willingness to help the environment found in females may be explained by a study done by McCright (2010) on how gender affects knowledge on and concern for climate change. McCright found that women generally have greater scientific knowledge about climate change than men and are slightly more concerned about climate change. Both these findings and our own differ from those of a study undergone by Demetriades and Esple (2009) about the gender dimensions of poverty and climate change adaptation, which reasoned that because of the poverty and disadvantages that women face around the world due to gender inequality, women were less likely to have the means to change their lifestyle to better help the environment. A possible explanation of why the findings of our study and those of Demetrides and Esple (2009) differed may be because while they studied women all around the world, our investigation focused on women within the continental United States, where gender inequality may not be as apparent as in other parts of the world. Understanding why different groups (such as males) are less likely to want to help their environment in the United States is crucial for helping us identify who, as a society, we need to focus on as a demographic with education about climate change and all the negative effects it poses. There could be a multitude of reasons as to why men in the United States are less willing to reduce their carbon footprint, but, regardless, it is important that this is acknowledged and used to help better educate people on the topic of climate change and the damage it causes.

The study also revealed that millennials, defined here as adults born between 1981 and 1997, are not more willing to reduce their carbon footprint compared to those in the older population (i.e., born before 1981). Similar results in terms of a lack of association between age (as a continuous variable) and willingness to reduce carbon footprint were found in the study done by Heath and Gifford (2006). This is quite interesting since it is expected and assumed by many that the older adult population would be more reluctant to the new ideas of the world, such as cutting-edge technology, new forms of entertainment, and ideas such as climate change. This however, was not the case, at least for the issue of willingness to reduce carbon footprint. Both those who were millennials and older were equally willing to reduce their carbon footprint. Nowadays people talk about "targeting the youth" as they are the future of our society. This finding illustrates that both the youth and the older population need to be equally targeted with information and encouragement to help the environment. A study similar to the one we carried out (Dickinson et al., 2016) investigated which moral foundations predict people's willingness to take action against climate change and found different results. According to their study, the younger participants were more likely to be willing to act on climate change. In contrast, a study undergone by Wiernik et al. (2013) found that older individuals are somewhat more likely to avoid harming the environment and conserve natural resources. However, to our knowledge the comparison of millennials versus the older population with respect to willingness to reduce carbon footprint is a novel aspect of this study.

During this investigation, the calculations were undergone twice: once with those who answered "neutral" for willingness to reduce carbon footprint in the "willing" category, and subsequently with these neutrals in the "unwilling" category. This allowed us to have a sufficient amount of data without having to reason neutrals into either the "willing" or "unwilling" category. We found that the two approaches produced very similar results in terms of the potential risk factors' associations with willingness to reduce carbon footprint. This information about the effect of methodology on results augmented our confidence in the conclusions and can be useful for future studies about this outcome of interest, as it shows that putting neutrals in the positive ('willing') or negative ('unwilling') response category would likely not affect the conclusions. Interestingly, there is a widely held belief of the "omission effect", which argues that people favor harmful inaction (which, in our case would be being "neutral") over harmful actions (which in our case would be unwillingness to reduce carbon footprint) (Willemsen and Reuter, 2016). This theory reasons that people will choose "neutral" rather than "unwilling to reduce carbon footprint" because it makes them look or feel more moral. This

would mean that most "neutral" responses carry a negative weight, and would thus make the most sense paired in the "unwilling" category. However, since our study found that it does not matter what category neutrals are paired with, it is unlikely that neutrals in our study carried a negative weight.

It is important to recognize the limitations of this study, such as sample population, demographics, and bias.The data being collected only in the continental United States limits its relevance on a larger scale. The results of this study only show the risk factors for willingness to reduce carbon footprint in the continental United States, although climate change is a worldwide issue. In addition to this, the demographic characteristics of the surveyed population also present limitations. Only adults (18 years of age and older) were surveyed and thus the results don't recognize younger people and children and their ideas on and role in the fight against climate change's ramifications. Another set of limitations that are important to note are those pertaining to biases that are common to observational studies. Information bias, although quite unlikely, could have occurred if an answer was recorded incorrectly. Selection bias may also have occurred if the proportions of different groups of people in the study sample don't align with the proportions of the same groups of people in all of the continental United States, which would make the odds ratios unrepresentative of the target population. Finally, confounding bias could have happened, which occurs when there is a factor not looked at in the study that is associated with a risk factor that was looked at in the study and the outcome of interest. This would cause the odds ratios between the risk factor in the study and outcome of interest to be incorrect.

5. Conclusion

During this study a multitude of interesting results were found that can assist in identifying the type of person most willing to reduce their carbon footprint, and how we can get more people to also be willing. Believing in climate change is a major positively associated risk factor for willingness to reduce carbon footprint. Thus, educating people on the topic of climate change is an important step towards having more individuals working to help the environment and working against climate change's harmful effects. In addition, being female serves as a moderate predictor for willingness to reduce carbon footprint, showing that somehow males in the United States need to be better targeted. Although there was no association between being a millennial and willingness to reduce carbon footprint, this finding still holds value as it shows that all adult age groups need to have attention directed at them in order for the most change to occur. Understanding what demographics in our society are most willing to reduce their carbon footprint and what demographics aren't willing, and thus need to be targeted, helps us work towards a world where everyone who is able to is contributing, as this will be most effective in combating climate change. Finally, we determined that when using Likert scale questions about willingness to reduce carbon footprint it does not matter whether the neutrals are sorted into the positive ('willing') or negative ('unwilling') response category. This methodological finding is significant not only because it strengthens our conclusion but it also allows for future studies to not have to lose valuable data by being able to keep neutrals through putting them in already existent categories without serious implications.

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Monitoring Deforestation Through Quadrotors in Pakistan

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Abstract

With its annual deforestation rate being one of the highest in the world, Pakistan is highly susceptible to climate change impacts. According to the Forestry Sector Master Plan, the levels of deforestation and forest degradation in Pakistan have reached high-danger levels, resulting in widespread flooding, soil erosion and extensive siltation of reservoirs and irrigation systems. As a result, the country is expected to incur an annual loss of Rupees 2.3 billion which can have a devastating impact on its already frail economy. While both local and international agencies have presented numerous solutions to tackle the issue of deforestation, it is imperative to first build a reliable system that allows experts to monitor, record and analyze the extent of deforestation in different areas within the country. Hence, it is crucial for Pakistan to bolster its forest monitoring system in order to detect the extent of the problem and devise a plan of action accordingly. Taking into the consideration the topographical constraints in Pakistan's diverse landscape, the research findings propose the use of quadrotors for developing an effective mechanism for accurate and cost-effective data collection in the monitoring and prevention of deforestation. The paper contains the analysis, comparison, and review of the two of the best methods that may be used to prevent deforestation in Pakistan. Hence, the study aims to address the following research question: "To what extent can quadrotors-driven methods be used to effectively monitor deforestation in Pakistan?" By comparing two distinct methods, factual evidence is provided to highlight the fact that quadrotors can be used to set up a cost-effective system to monitor deforestation in Pakistan through automation.

Keywords: Quadrotor, identification, GPS, Image, Deforestation, Monitoring

1. Introduction

Pakistan is considered to be among the list of countries that are most adversely affected by deforestation in the world. In its recent annual report, The Germanwatch Global Climate Risk has ranked Pakistan as the fifth most vulnerable country to climate change mainly owing to its rapid rate of deforestation (Afzaal, 2020). Deforestation can be defined as cutting of trees or plants to create space for something besides forests (Derouin, 2019). It is important to note that the existence of forests is essential for life on earth as it maintains the appropriate carbon level needed in the atmosphere, reduces soil erosion, provides habitat to wildlife, and protects coastal areas from floods and other natural calamities. In Pakistan, around 27000 hectares of forest area is cleared every year, which is among the

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quickest rate of deforestation in the world. Alarmingly, an entire forest area of Pakistan will vanish within the next 15 years if deforestation continues at this rate (UNDP, 2013).

According to Global Forest Watch, Pakistan lost 9.61kha of tree cover from 2001 to 2019, mainly due to shifting agriculture and forestry. The regions of Khyber Pakhtunkhwa and Punjab are mainly responsible for 90% of all tree cover loss between 2001 and 2019. Since less than 5% of Pakistan's total area is under forest cover, it is alarming to note that the rate of deforestation in Pakistan is about 1.5% on average (Saeed, 2003). While there have been numerous efforts to tackle the issue, a combination of factors including financial constraints, gaps in effective policymaking and corruption have led to the failure of Pakistan's government in presenting a viable solution to the problem. Most importantly, however, there is a significant lack of technological expertise in the field due to which Pakistan has failed to devise a cost-effective solution to monitor and prevent deforestation.

The use of Quadrotors to Monitor Deforestation

Considering Pakistan's financial restraints, there is a dire need for forestry experts to design a low-cost system to monitor deforestation effectively. In addition to that, the system must have the capacity to be implemented across Pakistan's diverse range of topographies. Considering these factors, the study supports the use of quadrotors as powerful and inexpensive data collectors to abate deforestation. A quadrotor is a small mechanical device which utilizes its four rotors for flight. In the context of Pakistan, there are two distinct methods that involve the use of a quadrotor to monitor and detect deforestation.

The first method involves a type of quadrotor that is fitted with a monocular camera and tele operated by the host to capture pair of images of trees using translational movement (Shah et al, 2017). The images are put into the convolutional neural network to detect trees and the network is inspired by the research of Redmon et al. (2016). The Stereo correspondence algorithm produces the depth and disparity map through the pictures (Yamaguchi et al., 2014). The algorithm is faster at generation of disparity maps compared to the other methods, like slanted plane method, that involve time-consuming optimization algorithms (Yamaguchi. et. al., 2012, 2013). This process is part of the database run. In the query run, the whole process ensues and the previously detected trees are associated (Shah et al., 2017). The method can be used to detect the missing trees automatically that may have been illegally cut. Importantly, this method can be ideal for the automatic detection of trees in the mountainous and inaccessible areas of Northern Pakistan ("Drones: the pros and cons for community-based monitoring | Forest Compass", 2020). This method is only able to accurately detect trees with straight trunks. Hence, further research must be conducted in Pakistan to improve the detection system for trees with bent trunks.

The second method relies on a quadrotor to capture high-resolution images by flying the device at certain height i.e. mostly around 250 meters above the ground (Paneque-Gálvez et al., 2014). The images of the same forest area are captured over a certain period of time (usually around 1 week) to gather the best quality time-series imagery for the analysis of forest loss (Paneque-Gálvez et al., 2014). The image collection system may be improved by assigning accurate location numbers to the images using the odometry data from the quadrotor.

Traditionally, forest monitoring and conservation activities in Pakistan involve teams of experts who personally visit forests to detect the extent of deforestation by collecting data. However, this approach is restricted to certain accessible areas. Moreover, teams of experts from the Forestry department are also often bribed by local elites, who are involved in deforestation, to falsify the data on deforestation (Shahbaz et al., 2011). Hence, the quadrotor-governed methods present the best solution to monitor deforestation in Pakistan as the process of data collection is both fair and accurate. Considering the geological conditions of Pakistan, both the quadrotor-driven methods can be used in particular areas in the country.

2. Method 1

The first method of monitoring deforestation through quadrotors involves using a device with a monocular camera attached to it. This approach to using this method comprises of three modules:

Tree Detection Module:

In this module, the monocular camera fitted on the quadrotor captures an image of a tree trunk. The image is fed into a deep convolutional neural network. Using details from the image, the network projects each bounding box and the input image gets split into a 7x7 grid. The grid cell takes responsibility of detecting an object, provided that the central part of the object falls within the grid cell. The network with 24 convolutional layers and with two linked layers outputs 7x7x31 tensor of predictions. The network is enhanced with Pascal VOC 2007, 2010, 2012 and the dataset of trees. More than thousand images, composed of more than 4000 trees, can be stored in the dataset (Shah et al., 2017). The trees that are in closest geometric proximity to the quadrotor get detected.

The findings of the module suggest that several trees can be detected in variety of lighting conditions and at different positions of the quadrotor (Shah et al., 2017). The system detects trees automatically without human intervention, which means that forests such as Alpine located on the steep terrains of Gilgit-Baltistan can be monitored through a quadrotor without much effort. In fact, this method is most suitable to observe the inaccessible forest areas located on the rugged topography of the Northern areas of Pakistan. Additionally, around four trees can be detected in a single translation through this method, which makes the recognition of trees relatively faster and less time-consuming.

However, since the detection method relies on the visibility of the trunk of a tree or stem of a plant, it is not possible to accurately monitor plants such as the Deodar Cedar which is found in the Khyber Pakhtunkhwa province, since its stem is covered due to its unique cone shape.

Depth Estimation & GPS Tag Calculation Modules

The goal of this module is the computation of dense disparity map through a quadrotor equipped with a monocular camera. In this module, the quadrotor takes the image of the trees at the position A, then performs a horizontal maneuver, and captures another image at the end of maneuver at the position B (Shah et al., 2017). The SPS Stereo (stereo correspondence algorithm) calculates the disparity map using the image pair (Yamaguchi et al., 2014). Further, to calculate the length between the quadrotor and the detected tree, the equation between disparity and depth is used (Gu et al., 2014). The relation is Z = f*(b/d) where Z is the straight line distance between plane of the camera and tree, f is focal length in pixels, b is the baseline obtained through the data from the motion sensors attached to the quadrotor, in meters, and d is the disparity of the points in pixels. Simple geometry and trigonometry are used to calculate the final distance and direction between the quadrotor and the detected tree (Shah et al., 2017)

To calculate the GPS tags, we require absolute bearing between tree's direction from quadrotor and the North. Knowing the absolute bearing, GPS coordinates of quadrotor, and the distance between the quadrotor and the detected tree, we find GPS tags using the formula (Shah et al., 2017):

$$\varphi 2 = \text{asin}(\sin\varphi 1.\cos\delta + \cos\varphi 1.\sin\delta.\cos\theta)$$

$$\lambda 2 = \lambda 1 + \text{atan2}(\sin\theta.\sin\delta.\cos\varphi 1, \cos\delta - \sin\varphi 1.\sin\varphi 2)$$

Where, θ is the bearing (clockwise from north), δ is the angular distance (d/R). Hence, this module tags all the detected trees on map with global coordinates.

The detected trees are tagged with global coordinates, which are stored in database. The formula is picked from the research of Shah et al. (2017).

Matching and Association module

This module deals with associating previously detected trees. The module involves identifying and matching the detected trees of database run with the identified trees of query run. As the quadrotor's Starting GPS location can vary in the database run and query run, the disparity map created can also be different (Shah et al., 2017). So, it is not possible to use relative geometric proximity in query run as it was used in first run. In the query run, it is preferable to use relative geometry between trees, which remains same in both the database and query run. Also the unique description of trees that was set up in database run may be used to identify the previously detected trees (Shah et al., 2017).

Relative geometry involves the distance and bearing between the detected trees. The process of association can accurately match the detected trees in both the database run and the query run. In fact, the process can provide precise matching of the detected

trees for more than 2 query runs. Most importantly, if any tree in database is not matched with the same tree in the query run, then the alert is sent to the authorities about the missing tree. This capability can be brought to use to keep check of deforestation of the Juniper forest of Baluchistan, where authorities are unaware of the illegal cutting of the trees until it is too late. Additionally, the GPS coordinates of the missing tree provide precise location of the area where deforestation is taking place. This information may assist forest conservation organizations to abruptly send their teams to the location and prevent further cutting. This means that the quadrotor not only helps in the detection but also in the prevention of deforestation. Without any doubt, the system is one of the fastest method to identify and locate deforestation in not just accessible but also the inaccessible mountainous areas of the Northern Pakistan.

3. Method 2

The second method to avert deforestation in Pakistan is the use of light-weight quadrotors to acquire high spatial-resolution imagery. The quadrotor moves a few meters (50-300m) above the forest cover and takes high-quality images (Paneque-Gálvez et al., 2014). The quadrotor with M600 pro drone aerial imaging solution as the camera system can be used to take photographs of the forest cover since it allows swift rotation of its camera to provide a variety of camera angles for analysis ("*Drone With Cameras | Phase One Industrial Drone Solutions*. industrial.phaseone.com", 2020). The pristine images are sent to the host system, which is a control room where the images are saved for future analysis. Further, the host system tags the time when the picture of the forest cover is received by the host system.

The whole process continues after short intervals of a few days to gather high-resolution time-series imagery of the same locations that would permit detailed analysis of the loss of trees due to the illegal cutting (Paneque-Gálvez et al., 2014). The assessment is usually done by a team of environmental engineers. However, since the images of different forest areas may be analogous, it may be difficult to identify the exact area where the deforestation has taken place. Hence, the system of the image collection can be improved by assigning the accurate location number to the images in the control room using the GPS coordinates of the quadrotor when the quadrotor takes the picture. In this way, forest analysts can uniquely identify each forest area and locate the specific area of our interest.

This method of data collection is way faster than the traditional method of physically sending experts to different areas to monitoring forests in Pakistan. Additionally, the quadrotor collects accurate and fair data while the forest management teams can often be bribed by rich rural landlords, who are involved in the illegal cutting of the trees to record false data. The quadrotor-aided monitoring is less expensive than the traditional techniques, which will contribute to reducing the financial expenses of the government of Pakistan. However, the approach requires the quadrotor to fly at a height of approximately 250 meters above the ground. The height makes it problematic to control the flight of quadrotor in the coastal areas of Sindh where wind speed at certain height can reach over 48 kilometers per hour (kph), which is the highest wind speed at which most of the commercial quadrotors can fly safely. The coastal areas of Sindh have mangrove forests that are widely deforested due to the increased demand for timbre.

4. Results and Discussion

An experiment was conducted at a campus of Indian Institutes of Technology (IIT) in India by a team of researchers to investigate the effectiveness of the method used to automatically detect deforestation using deep neural network. The table below presents the results from the experiment.

The tables provide the results of the experiment that used convolutional neural network. The false positives in the database run in Table 1 signal the detection of the vertical trunk like figures such as poles, while the false negative represents the failure of the Convolutional neural network in identifying any tree which may have a bent-shaped trunk. The mean error shows the average difference between the actual length in between the trees and the length calculated using the assigned GPS coordinates (Shah et al., 2017).

Table 1 : Database Run statistics

Location	Number of trees	Number of detected trees	False positive	False negative	Error in m	
					Mean	Variance
1	43	41	0	2	0.4666	0.0511
2	31	32	1	0	0.3824	0.0439
3	26	25	0	1	0.4320	0.0476

Table 2: Query Run statistics

Location	Total trees	Trees detected in database run	Trees detected in query Run	False positive	False negative
1	43	41	41	2	0
2	31	32	31	1	0
3	26	25	24	0	1
1	38	38	37	1	0
2	27	27	27	0	0

In Table 2, the false positive or negative indicate the error in association with the query run. Remarkably, the network was able to identify the trees that were detected in the database run but were missing in the query run (Shah et al., 2017). The results suggest that the system can be used efficiently against the deforestation of those trees which have straight trunks.

In the context of Pakistan, irrigated plantations in Sindh and Punjab such as the Riverine forest along the river Indus and the Alpine forest in Northern Pakistan can be accurately monitored through quadrotors to control the deforestation of trees. Also, the movement of quadrotors is not restricted due to the irregular or rugged topography of Northern Pakistan, allowing the monitoring of forests to be carried out even in the mountains of Pakistan.

For other trees with bent trunks, the method should be thoroughly studied and improved. The false positive error, though less significant, can be eliminated if the convolutional neural network is bolstered to employ other features like branches and leaves to identify trees. The use of several characteristics of a tree will not only afford the detection of trees with extremely bent trunks but also the identification of the plants with covered stems as in the case with Deodar Cedar plant whose stem is invisible due to its unique cone shaped structure. For the trees with straight trunks, the process of the automatic identification will be extremely helpful and will introduce a new generation of the forest monitoring system.

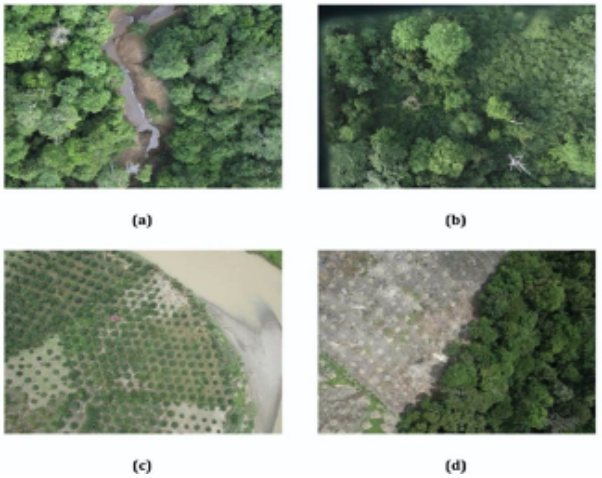

Figure 1 Examples of imagery gathered by small drones that show the extremely high spatial resolution that can be achieved. (a) Danau Girang (Sabah, Malaysia); (b) Chitwan National Park (Nepal); (c) Palm oil plantation by river (Indonesia); (d) Recently logged forest (Indonesia). Imagery provided by ConservationDrones.

The figure above shows the images captured by the high-resolution camera on the quadrotor. The results show that the quadrotor can take clear images of forest cover to allow forest conservation organizations to analyze the collected data. As the pictures indicate, even the small gaps in the forest cover can be identified effortlessly, allowing experts to locate deforestation in a particular area after comparing the previous images of the same area. Cloud cover does not affect the working of the procedure since the quadrotor flies below the clouds, and assessment of forest can be carried out all year, including rainy seasons (Evans, 2020).

Comparison of two methods

While the discussed methods can be important in forest conservation, advantages and disadvantages of both of the methods should be considered for effective implementation. Method 2 requires a Quadrotor to fly and take images at the height of 300 meters: such a high flight in coastal areas may cause flight of Quadrotor to be unstable due to high wind speed. However, method 1 involves the quadrotor to fly at low height (approximately at the level of a tree trunk), so wind may not affect flight. Hence, method 1 can be more suitable in coastal areas of Sindh and Balochistan. Further, method 1 may not work well to detect trees with bent trunk, but method 2 can allow monitoring of trees with bent and straight trunks. Although both the approaches are fast, method 2 is faster as it allows large chunks of trees to be monitored with a single aerial image compare to four trees in a single translation through method 1. Additionally, method 1 relies less on human intervention than does method 2. This is because method 2 comprises analysis of the reduction of forest cover by environmental engineers whereas deforestation is automatically identified through method 1.

Both the methods discussed above use quadrotors for operation but using different techniques under different conditions. This difference is essential as Pakistan has an extensive variety of conditions including tall mountains in the North and deserts in the South. Thus, both methods can be used alternatively for the same purpose of preventing deforestation depending on the topography of the forest area under consideration. It is important to note that there is a need to conduct further research on this topic in Pakistan so that forest conservation can be improved and modernized through latest technology such as the use of quadrotors. In fact, other innovative ways of using quadrotors for reducing deforestation in Pakistan should be also be worked out. Until then, the authorities must consider the discussed methods for the aim of preventing deforestation in Pakistan.

5. Conclusion

Since Pakistan has one of the highest deforestation rates in the world, it is crucial for authorities to strengthen the country's forest conservation system by using innovative technologies such as the use of quadrotors. The study provides a comprehensive overview of the extent to which quadrotors can be used in monitoring deforestation and consequently, halting the illegal cutting of trees. The aforementioned discussion provides factual evidence to highlight the fact that quadrotors can be used to set up a cost-effective system to monitor deforestation in Pakistan through automation. However, there is a definite requirement to conduct further research into analyzing the implementation of a quadrotor-controlled tree detection system in Pakistan to ensure that this technology presents a reliable monitoring system which is best suited to the environmental and topographical conditions of Pakistan. However, it is certain that in the future, quadrotors can contribute towards a significant reduction of deforestation due to illegal cutting of trees in Pakistan.

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