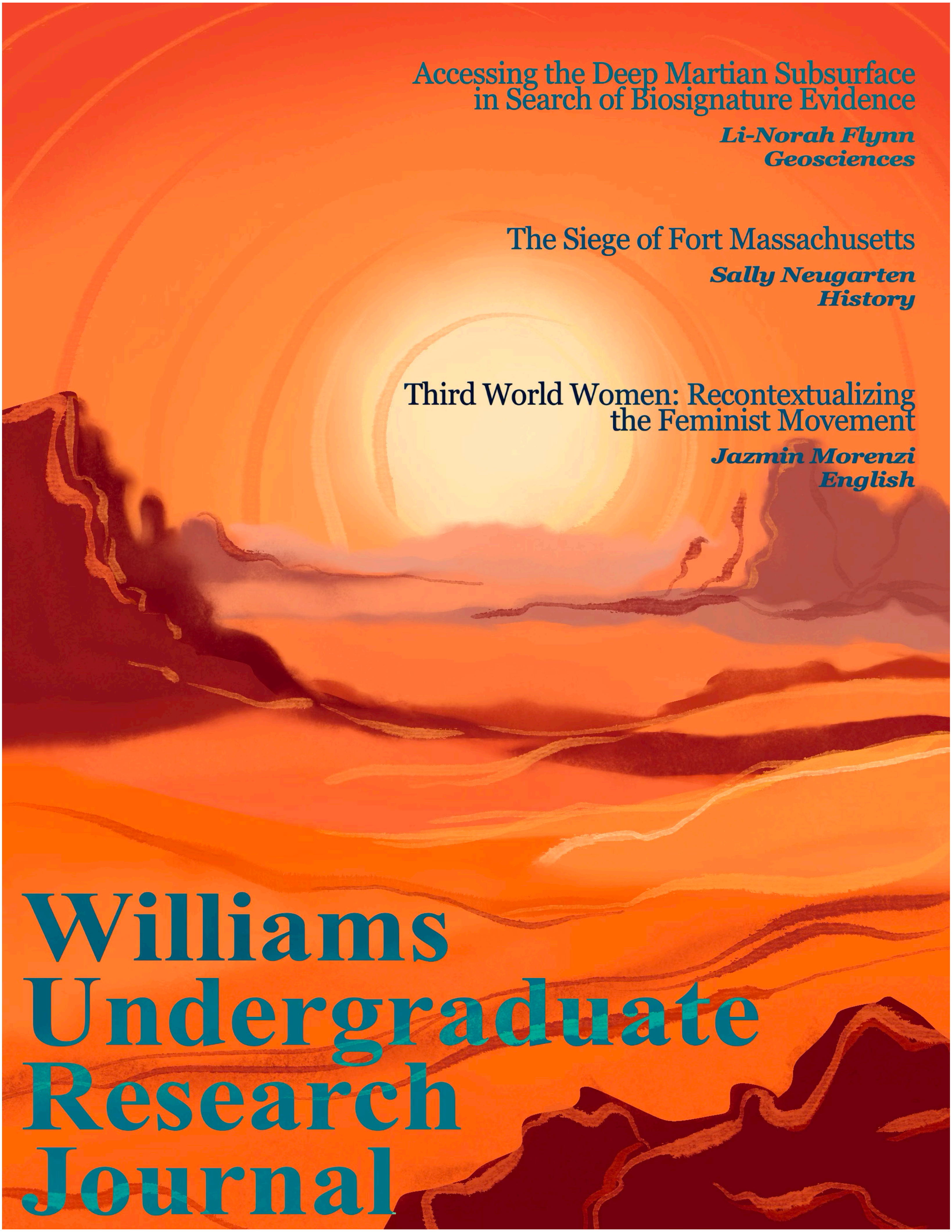

Accessing the Deep Martian Subsurface in Search of Biosignature Evidence

Li-Norah Flynn
Geosciences

The Siege of Fort Massachusetts

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History

Third World Women: Recontextualizing the Feminist Movement

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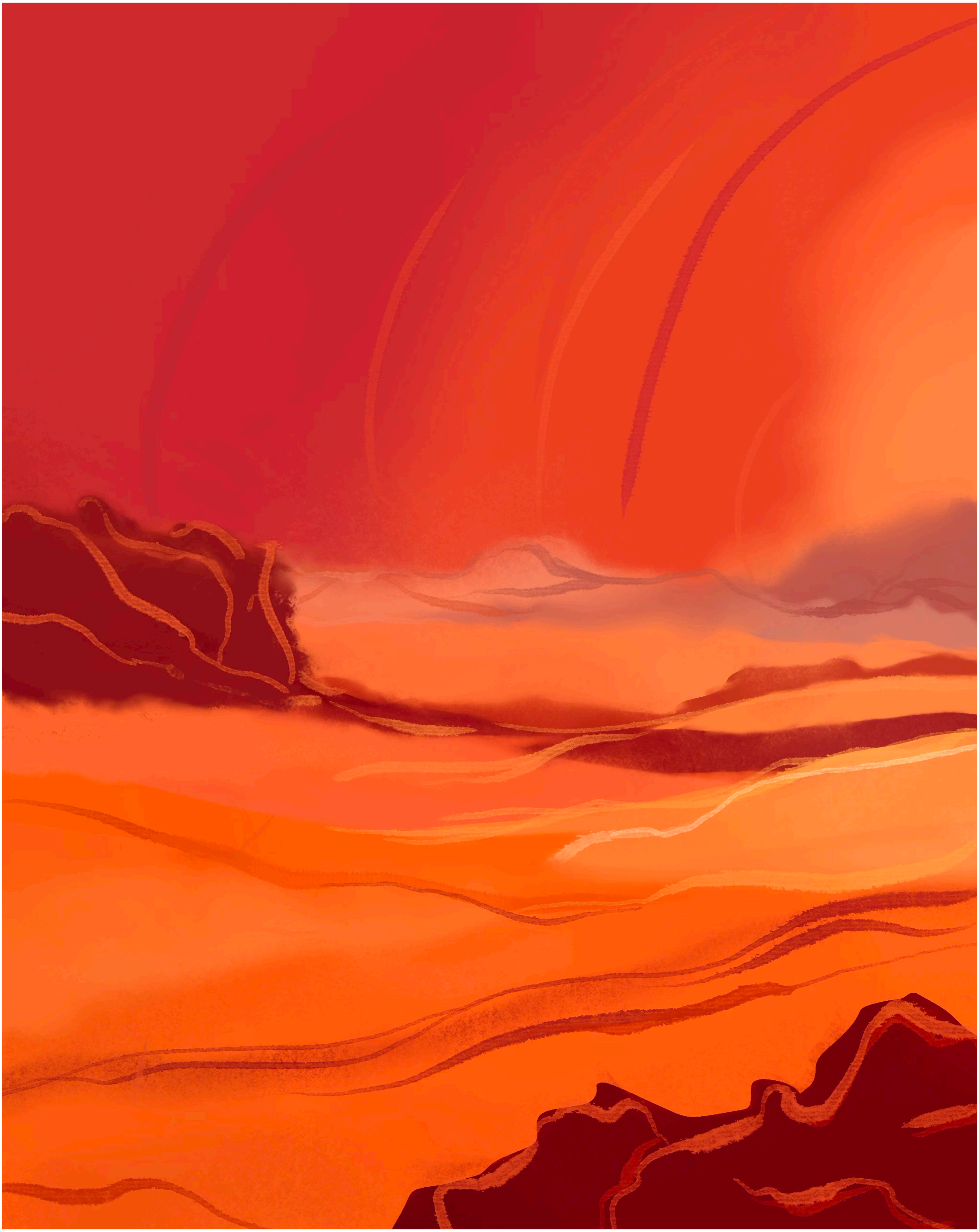
Williams Undergraduate Research Journal



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Dear Reader,

It is my honor to present you with the fourth edition of the Williams Undergraduate Research Journal (WURJ), Williams College's first and only peer-reviewed journal highlighting student research across academic disciplines. Even though more than half of Williams alums go on to pursue higher education,1 prior to 2020, there was no platform on campus for students to (1) share their research in a formal manner, nor (2) get experience in the all-too-common academic publishing process. WURJ was established to fill this gap by helping students disseminate their exceptional work conducted both independently and for classes and labs.

Throughout the years, WURJ has evolved into so much more than a journal and has adopted the mission to demystify research and academia at Williams. This fall semester, WURJ held its second annual Student Research Panel. This event was a tremendous success with many attendees from all academic years coming together to hear fellow Williams students describe their unique research experiences in the natural and social sciences. We took this opportunity to release the previous edition of the print journal, open submissions for this publication, and share our ongoing partnership with the Office of Institutional Diversity, Equity, and Inclusion to promote the work and visibility of students underrepresented in their fields of study. Building on last year's efforts, WURJ hosted a series of small group dinners this spring with faculty from historically underrepresented backgrounds in their respective fields. The dinners facilitated honest conversations about academic life with an emphasis on how to navigate the ivory towers as an underrepresented scholar. Through these intimate small-group discussions, we provided students with faculty and peer contacts who they can lean on as they enter and grow in academia.

Following Williams' liberal arts spirit, we selected articles for this fourth print edition that highlight both the breadth and depth of academic work being conducted by students at the College. Many of these works have been adapted from projects for classes, independent studies, and theses. I strongly encourage any Williams student interested in getting published to visit our website (sites.williams.edu/WURJ) for more information.

The papers in this issue cover topics ranging from planet-protecting methods for accessing the Martian subsurface to the profound local history of the land Williams currently occupies, all presenting valuable and widely different perspectives for understanding and interpreting our world. It is my sincere hope that after reading this journal, you come away not only with new knowledge on a diverse range of subjects, but also an increased curiosity for the concepts mentioned within.

I would like to express my deepest gratitude to all of the students serving as authors, editors, graphic designers, and board members of WURJ, as well as the faculty and staff who have committed their time and effort to help us achieve our goals. Without further ado, I hope you enjoy this latest edition of WURJ.

Sincerely,
Daniela Galvez-Cepeda
2023-2024 WURJ President

Note
1. *Fast Facts About Williams*, Williams College Office of Communications

letter from the president

2023-2024

Identifying the Most Practical and Planet-Protecting Method for Accessing the Deep Martian Subsurface in Search of Biosignature Evidence

Li-Norah Flynn

Abstract

There is no current indication of past or present life on Mars. To successfully search Mars for biosignature evidence, access to the deep Martian subsurface is required, as here, potential biological molecules are protected from cosmic and UV radiation from space, wind and dust storms above the surface and subsurface isotopic radiation is also minimized. The cold and stable environment below the surface, and also deep within Martian polar ice, also contributes to ideal preservation conditions, effective for billions of years. Previous Mars missions have only drilled as deep as 7 cm, and virtual imaging of the subsurface has only reached up to 80 m, so a new mission and mechanism is needed to investigate and extract samples from depths in the order of 102 to 103 meters, where evidence of life is most likely to be preserved. Physical samples are needed for thorough analysis of the subsurface, whether this be in situ, at the surface, or in a laboratory on Earth. While logistical practicality is vital in planning a mission to Mars in search of biosignature evidence, protection of the planet from the physical effects of human activity is paramount too, and so is the protection of Earth and Mars from microbial contamination. In this paper, these factors are numerically evaluated for six different deep access methods, using a comprehensive rubric. The final scores indicate that the Inchworm Deep Drilling System is most likely to successfully search the deep Martian subsurface for biosignature evidence, although it has some limitations. This study nonetheless identifies several vital considerations that future missions must consider before exploring the deep Martian subsurface.

Introduction

The lack of present indication that life exists on the surface of Mars is partly due to the lack of a substantial, stable atmosphere (Atreya, Gu 1995) and of a thick, shielding magnetic field (Acuña et al. 1998). This leaves the planet's surface vulnerable to the direct effects of cosmic and UV radiation, which cause the decomposition of organic and biological material, if it were to exist on the surface Mars (Friedmann and Koriem, 1989). Nonetheless, gamma (cosmic) and UV radiation cannot penetrate far into the ground beyond a few meters (Dartnell et al. 2007), so it is possible that biosignatures may be preserved in the Martian subsurface or in Martian Ice (Kminek, Bada 2006). The subsurface is also protected from above ground conditions such as wind, that further contribute to the depletion of biosignatures (Moreau, Muller 2003). The cool, dry conditions of Mars (Bada, McDonald 1995) and its mineralogy (dos Santos et al. 2016) also aid the effective, longstanding potential preservation. It is also possible that the quantity and intensity of irradiation caused by radiogenic isotopes within the subsurface is insufficient to cause the depletion of biological molecules such as amino acids (Dartnell et al. 2007, Kminek, Bada 2006). The potential for the existence of water in the Martian subsurface (Westall et al. 2015) and the greater porosity of these depths (Michalski et al. 2018) also provide promising conditions for supporting life.

Therefore, accessing the Martian subsurface is a necessary step in identifying the existence of life on Mars (Kminek, Bada 2006). Yet no plan or method to carry this out has been established, although several theoretical ideas and mechanisms have been proposed. There are a number of vital considerations that must be made before implementing one of these projects, including practical feasibility. For the method to be possible in the foreseeable future, the equipment must have the appropriate technology to operate with minimal or remote human control, as we are far from conducting a human Mars mission (Salotti, Heidmann 2014). Additionally, as the present knowledge of the composition of the Martian subsurface beyond 20 meters is scarce, partially due to the limitation of radar imaging (Li et al. 2022), it is very possible that instruments will come across unexpected physical and chemical obstacles that will obstruct their functionality. For example, there may be unknown environmental chemical and physical effects on the instrument's mechanisms (Blake et al. 2012). Furthermore, the physical extraction of samples is necessary to fully analyze the subsurface for biosignatures, so methods must take precautions to preserve and protect samples from alteration under external conditions, during excavation and analysis. It is also vital that methods consider the principle of Planetary Protection which states that the study of extraterrestrial environments must not interfere with extant or existing life that may have developed there. One major concern is forward and backward microbial contamination (Frick et al. 2014), but also the extent of the physical traces of human activity left on the planet.

Thus this literature based research identifies the most practical method to access the deep Martian subsurface to search for biosignature evidence, while adhering to the requirements of Planetary Protection. In particular, this study focuses on potential methods previously proposed by scientists that aim to reach significant depths of 100m to a few kilometers below the surface or more, due to the enhanced likelihood of finding biosignatures here (Westall et al. 2015). However, previous Mars missions have only drilled as deep as 7 centimeters (NASA/ JPL-Caltech) and high resolution imaging has only reached up to 80 meters deep (Li et al. 2022). Thus it has been proposed that there should be at least two future missions to Mars with the aim to reach penetrating depths of approximately 300m and 3 km respectively (Mancinelli 2000), and thus this study will focus on this range. This study aims to tangibly evaluate all of these proposed instruments and technologies using a quantitative assessment rubric as a standard.

Methods

Data Compilation

Literature articles that include depths between 100 m and 3 km are compiled, due to the pre-discussed increased likelihood of finding biosignatures at these depths. The search for biosignatures in the subsurface is dependent on the ability to obtain samples that can be analyzed (Anderson et al. 2012) and as a result, I use studies that propose physical methods of reaching the subsurface, such as drilling, over remote sensing methods, for example. The proposals examined in this investigation are chosen to show a diversity of mechanisms and instrumentation, from thermal probe coring to deep borehole drilling (Mancinelli 2000), as this provides a more comprehensive picture of the all possibilities of accessing the Martian subsurface. Using a wide variety of authors, opinions and perspectives also enables a holistic perspective of all concerns associated with physically penetrating the surface of Mars, allowing a more critical evaluation of the included studies. More recent publications are used as they consider and improve upon errors or insufficiencies in previous studies, as well as they take into account the limits and possibilities of most recent technology (Sanders et al. 2015).

Analytical Framework

First I examine the methods in the selected articles based on practical feasibility, to conclude if it is physically and logistically possible to carry out. This is based on factors including the time the project will take to plan and finalize (Zubrin 2011) and the ability for the mission to operate with remote human control (Choate, Jaffe 1973). As humans are not expected on Mars in the near future due to the extent of planning required (Portree 2001), a mission is presently more feasible if it does not require physical and direct human intervention. Other considerations are the sizes of instruments, the physical properties and composition of the Martian surface and subsurface (Spohn et al. 2022) and the ability of instrumentation to maintain function over a large range of temperatures, pressures and UV radiation exposure (Sobrado et al. 2014). Part of my evaluation of each method is based on how easily these proposed methods can overcome such obstacles based on past and possible future research.

I then assess the possible consequences of extracting samples in preserving the potential biosignatures contained in them. For example, exposing the subsurface to gasses, radiation and the conditions of the atmosphere and space via drilling can result in the destruction or loss of biosignatures in a sample (Allen et al. 1999). This can occur by reactions such as thermal decomposition when using thermal analysis or probes (Archer Jr et al. 2013), or by the physical loss of shielding (Röstel et al. 2020) when the surface is excavated. I evaluate the method's precautions taken and potential ability to prevent these risks.

Next I use a rigorous interpretation of Planetary Protection to evaluate if these methods will 'interfere with extant or existing life that may have developed [on Mars]'. Part of this evaluation includes the consideration of preventing both forward and backward contamination (Rummel 2001, 2004), and also the possibility of the instruments leaving an irreversible and permanent impact on the physical Martian landscape, such as leaving deep excavation holes. The possible destruction of biosignatures mentioned above is also relevant to Planetary Protection. If the method poses unavoidable harm or threat to the planet and potential evidence of life, then it should strongly not be considered (McKay, Davis 1989). Humans do not have the right to interfere with the biotic environment of any planet (Zacney, Cooper 2006).

Weighting of each factor is dependent on their necessity in formulating a successful mission that searches the deep Martian subsurface for biosignature evidence. Planning and finalizing is of little weight as this can easily be changed by the amount of resources invested into research and space exploration. The physical access factors, including size of instruments, maintaining function over changes in physical conditions and autonomous operation are slightly more important as they determine if it is physically possible to carry out and operate on Mars. However, they are not weighted too high as they may be adapted in the near future given the pace of present scientific research. Preservation of samples before or during extraction and analysis is more important, as this factor is a key in determining if biosignatures do exist, the primary goal of this study and of the potential future mission. Sterilization is also of little weight as it is presently under intense examination and research by scientists, so the actual success of possible sterilization methods is still yet to be fully determined. Also, it is not always necessary for samples to be taken back to Earth if thorough analysis can be performed on Mars, so sterilization to prevent backward contamination may not be needed. Alteration to the Mars environment is weighted slightly more as physical pervasion of Mars should be minimized, otherwise humans may get too complacent or comfortable with exploiting foreign terrestrial bodies, which then leads to several, much larger issues.

Evaluation

Finally, I give a rating out of 5, using the rubric, for each of the categories described above, for each method. I then combine these ratings to determine how practical the method is while simultaneously meeting the requirements of Planetary Protection. I then establish the proposal with the highest rating and explain how it meets the necessary criteria, but also where it falls short and how it can be improved.

Rating Rubric

Practical Feasability

Factor	Weight	5	4	3	2	1
Time to plan and finalize	10%	Already successfully and widely used on Earth and is easily applicable to Mars/ Mars conditions have been tested on this method	Already successfully and widely used on Earth but needs modifications to apply to Mars	Is a promising method that requires further refinement with presently possible technologies	Is reasonable but requires further refinement that no present technologies are able to complete	Is an unreasonable method that requires a significant amount of further work and research
Size/practicality of instruments required	15%	Small, lightweight, practical	Slightly impractical but can be easily adjusted to become more practical	Impractical in size and weight but can be adjusted with considerable modifications/ work	Impractically large OR heavy, cannot easily or foreseeably modified	Impractically large AND heavy, cannot easily or foreseeably modified
Maintaining function over changes in physical conditions	15%	Is able to withstand or accommodate for extreme radiation, pressure, temperature and physical changes with depth into the subsurface	Is able to withstand most extreme physical changes and is easily modified to do be fully effective for ALL extreme condition changes	Is likely to withstand some of these physical changes but may not be able to survive under extreme conditions	Is not able to withstand most of these physical changes	Will not be able to withstand any of these physical changes
Operate without direct human intervention	15%	Requires no human intervention to operate, remote or direct	Requires some remote human intervention to operate	Requires significant/constant remote human intervention to operate	Requires some direct human intervention (a few humans on Mars) to operate	Requires a large team of humans on Mars to operate
Preservation of sample/ biosignatures	20%	Samples will be protected from radiation, pressure, temperature and physical element exposure	Samples can easily be protected from these conditions using present mechanisms/ technology	It is likely that the method can be modified to successfully protect samples with future technologies	It will be extremely difficult to protect samples, even in the future	It is not presently nor foreseeably possible to protect samples with this method

Planetary Protection

Factor	Weight	5	4	3	2	1
Sterilization/ prevention of backward and forward contamination	10%	Is presently able to prevent forward and backward contamination easily by sterilization, for example	Can be easily adapted to be sterilized/ to prevent backward and forward contamination using present technologies/ methods	It is likely that the method can be modified to be successfully prevent backward and forward contamination with future technologies/ methods	It will be extremely difficult to prevent backward and forward contamination, even in the future.	It is not presently nor foreseeably possible to protect samples with this method
Alteration to Mars environment	15%	Will create little to no alteration to landscape and little to no effect on wider environment	Alteration is small but has some effect on the wider environment, though not necessarily harmful	Moderate, permanent alteration that is likely to be harmful to environment	Alteration is significant, permanent and harmful to environment	Creates very large scale, harmful, permanent damage to landscape, severe harm to environment

Results and Discussion

Vertical Drilling

(Langhoff, S. R., 2008)

Overview

Vertical Drilling is a method that has been used readily on Earth since the late 20th century. The deep drilling tool has a drill bit which rotates to penetrate the ground It has a hose in the drill pipes that keeps the drill cool and the borehole open under the intense pressure that the drill experiences as it reaches greater depths. One of the primary purposes of deep borehole drilling is for access to oil resources beneath the Earth's surface. On Earth, depths of several kilometers have been reached using various drilling techniques, so this method is useful in understanding how to access the deep Martian subsurface. Another purpose of drilling to such depths into Earth is for scientific research, in particular to study rock samples and to unearth fluids and microbial life preserved in them, so this method may be important in finding how to search the Martian subsurface for biosignatures and microbial life also.

Practical Feasability

Time to plan and finalize - 4

While Vertical Drilling has been used for several decades on Earth, there are several untested challenges that drilling on Mars will encounter, such as low gravity, large temperature fluctuations, dust storms, and the presence of water-ice in the subsurface. Technological challenges include information transmission delays between remote human operators on Earth and the drilling machinery on Mars, of as large as 20 minutes one way, as well as the limited power and mass of a large scale drilling device on Mars. The colder, drier conditions on this planet also enhances the compactness of the surface and subsurface, meaning it is physically harder to drill into than on Earth. The main principles of vertical drilling on Mars do not need much planning, although some modifications are required for the drill to be able to withstand unforeseen environmental obstacles that are not present on Earth.

Size/practicality of instruments required - 1

To get to depths of several hundred meters as proposed by this study, extremely large machinery is required for vertical drilling into the surface of Mars. Human operation is presently necessary to perform deep borehole drilling. as autonomous drilling has not yet comfortably been developed on Earth. Presently, getting instruments this large on Mars has not yet been achieved, but this may be possible with future research.

Maintaining function over changes in physical conditions - 4

Large scale drilling is able to maintain function with pressure and temperature changes deep into the Earth's surface, so it is possible that the same can be applied to Mars. As mentioned above, the main unprecedented potential challenges the drill will face are the compactness of the Martian surface, low gravity and dust storms. These conditions should be tested on Earth to ensure the machinery can operate on Mars. Large temperature changes, water ice and hard materials can be effectively overcome using the current durable Earth-drilling machinery.

Operate without direct human intervention - 1

Deep borehole vertical drilling on planetary surfaces is presently and foreseeably only practical with human involvement. Independent or remote operation is possible only on a small, shallow scale, as performed by Curiosity and other Martian rovers (Tang et al. 2022). NASA believes that autonomous drilling could reach depths of 40-50 m with appropriate modifications, but human intervention is necessary to reach the depths that this paper examines. Again, autonomous deep drilling has not been fully and comfortably established on Earth.

Preservation of sample/ biosignatures - 2

With such large and heavy machinery, it is extremely difficult to obtain precision and care when drilling into a planet's surface. Thus the act of drilling can destroy biosignatures physically. Deep borehole drilling also exposes the subsurface to exterior conditions such as radiation and temperature and pressure changes. This exposure will cause damage to biological molecules and can also cause harm to potential non-biological biosignatures. There has been little to no conversation about how vertical drilling can be adapted to protect samples in the surface from these exterior conditions but it is not something out of the reach of modern science.

Planetary Protection

Sterilization/ prevention of backward and forward contamination - 2

Due to the size of vertical drilling machinery required for the purpose of accessing the deep Martian subsurface, sterilizing equipment is extremely difficult, both before arriving on Mars and before returning to Earth. Extreme care is needed to fully ensure that all exterior and interior surfaces are free of contaminants, which is time consuming and impractical over such a large instrument. It is likely that additional instrumentation would be required to ensure this. The current protocol for prevention of sample contamination from extra-terrestrial bodies includes double vacuum sealing and containment (Race, M.S. 1998), but this cannot be easily applied to a huge drill. Requiring a container for this instrument adds to the weight and size of equipment needed to deploy this method, thus enhancing the impracticality of it.

Alteration to Mars environment - 1

This method will leave a large, permanent physical mark on the planet's surface. Vertical drilling will cause deep and wide excavation scars such that the planet's surface cannot be returned to its original state. Furthermore, as it is likely that many drilling locations will be needed to search for evidence of life, there will be an extremely widespread footprint of human damage left.

Score: 2.05

Plasma Drilling

(Tang, X. et al. 2022)

Overview

Plasma drilling uses a thermal melting probe to drill into the vast amounts of water ice present at the poles of Mars. Drilling into this ice will help scientists to understand the climate of Mars during the Amazonian period, and isotope identification can be used to determine the likelihood of past life existing. It is also possible that biosignatures can be preserved in ice. The heated probe is able to melt the ice to access depths of up to 2 km. The cracks in the Martian ice increase its surface area, meaning that the ice is much less thermally conductive, making it easier to penetrate.

Practical Feasibility

Time to plan and finalize - 5

This is a method that has been preliminarily tested under both Earth and Mars conditions, and has been so far successful, so there is not much more planning and finalizing required to make plasma drilling practically possible on Mars. These test conditions include a vacuum vessel system, ice plate, controlled liquid nitrogen cooling, different ice porosities and a carbon dioxide feed-in. A large amount of power is required to operate thermal probes, so while it is feasible to carry out, the probes require modification to become more efficient before actual deployment.

Size/practicality of instruments required - 2

To obtain depths of several hundred meters or more, large equipment is required. As with vertical drilling, it would take significant effort to get such large equipment to Mars and back effectively and safely.

Maintaining function over changes in physical conditions - 4

Previous testing of plasma drilling equipment in a variety of conditions enhances the likelihood of the drills to maintain function over changes in physical conditions. Thermal conductivity of the probes have been tested or modeled under pressures of various possible porosities in the Martian ice, as well as temperatures as low as negative 100 degrees celsius. As the probe operates by melting through the ice, the main obstacle from the deep ice environment is the presence of sediment through which the probe cannot penetrate. Another major consideration is the probe being able to continually remain heated to a high temperature despite the freezing conditions surrounding it. A temperature control subsystem, as well as a pressure control subsystem, should be incorporated as part of the drill's design.

Operate without direct human intervention - 1

Again, the size of the machinery required means that direct human operation is needed for drilling at this scale. The probe also requires a large amount of energy to operate, and this deep into the ice, light and heat are not sustainable sources of energy. Thus it may require human intervention to ensure the instruments are properly powered over time.

Preservation of sample/ biosignatures - 1

The major issue is that the thermal probe is heated and therefore can permanently destroy any biosignatures or structures indicative of life. The high temperatures of the probe can cause the destruction or decomposition of isotopes or organic or biological molecules.

There is also no current method or precaution in place to prevent exposure of the subsurface to harmful radiation from space and other exterior conditions during drilling or extraction. Bringing a sample to the surface for analysis exposes it to radiation but also situates it in warmer temperatures which may affect its preservation.

Planetary Protection
Sterilization/ prevention of backward and forward contamination - 2

Again, due to the size of instrumentation required, it will be difficult to prevent forward or backward contamination by ensuring all equipment is sterilized or can be contained. As with samples, they are harder to sterilize given that compounds are preserved in solid ice and may need to remain in this state to be analyzed. Temperature control may be required for the sample to be extracted and transported, which can interfere with sterilization of the sample.

Alteration to Mars environment - 3

With ice drilling, there is no significant damage done to the physical geology or permanent landscape of Mars. However, solid ice has existed at the Martian poles for several billion years, so plasma drilling will destroy some portion of the ice landscape on Mars. On the other hand, plasma drilling does not need wide excavation holes to reach large depths.

SCORE: 2.40

Impact Excavation
(Cockell, C. S., Barlow, N. G., 2002)
Overview

Also known as 'nature's drill', impact excavation uses impact craters to access deep below the surface, without any need of human mechanisms. Simple craters can be used to examine depths as great as 270 m, but complex craters, which show more details than simple craters, are able to reach as deep as 6 km or more. These depths are dependent on the diameter of these craters, many of which originate from the heavy bombardment period, around 3.8 x 109 years ago. Small, shallow samples can be taken from the surface of these craters, or loose material that has been excavated by the impact itself - the ejecta blanket - can be collected for examination for biosignatures.

Practical Feasibility
Time to plan and finalize - 5

No complex, new technologies or methods are required to reach these significant depths, as no deep human penetration of the surface is used. Present surface exploration and shallow sample extraction methods can be applied to these craters. Complex craters can be targeted as landing sites for rovers and small samples can be taken out of the crater surface, from drilling as shallow as the 7 cm previously achieved by Martian rovers. These samples will be representative of depths of several hundred or thousand meters below the surface. Similarly, the ejecta blanket can be analyzed, in which no penetration into the surface is required at all. It may be possible that a rover presently on the surface of Mars can relocate to these craters and perform this sample extraction or analysis, without the need for another mission.

Size/practicality of instruments required - 4

The size of past rovers on Mars, including NASA's Sojourner, Curiosity and Perseverance, are suitable for this method, so using a rover to complete this exploration, shallow penetration and analysis is certainly practical. Rovers are small enough to easily traverse the terrain of Mars. The main concern is the ability for the rover to travel up and down steep slopes to access the base of the craters, considering some are deeper than 6 km. The Opportunity rover launched in 2003 failed to overcome a slope of 32 degrees on the Martian surface (Webster, G., Brown, D., Cantillo, L., 2016)

Maintaining function over changes in physical conditions - 5

Considerations when collecting material from the ejecta blanket include the mass and weight of individual pieces of sediment. The mechanism required to collect the loose material does not need to overcome severe changes in environment such as pressure and temperature. For drilling a few centimeters into the crater surface, there is no significant change in pressure or temperature. Rovers on Mars also have the ability to traverse over difficult and uneven terrains and withstand environmental changes such wind and dust storms. One obstacle is the unknown physical properties of subsurface materials in these craters; they may be too compact or hard for a small drill to penetrate.

Operate without direct human intervention - 5

Again, the success of previous rovers on Mars in operating, exploring and taking small samples without direct human intervention enhances the likely success of using impact craters to access the subsurface. Enhanced technology can be implemented if rovers cannot access the base of the crater due to slope or terrain, or cannot penetrate the ground due to surface hardness or size of loose material, for example. Direct human intervention is of little necessity in making this method successful.

Preservation of sample/ biosignatures - 1

A major concern of this method is the preservation of potential biosignatures on the surface of these craters and in the ejecta blanket. As this layer of the Martian subsurface has been exposed to exterior environmental conditions for billions of years, including weather and temperature changes and UV and cosmic radiation, it is highly likely that biosignatures excavated from impact and existing a few meters deep into these craters, would have been destroyed. Planetary Protection

Sterilization/ prevention of backward and forward contamination - 3

By using rovers already on the surface of Mars to collect and analyze samples, or by using new, future rovers and present sterilization techniques, forward contamination can most certainly be prevented. If samples are to be returned to Earth, success of sterilization to prevent backward contamination is more complex; it is uncertain what kind of biosignatures or molecules will be contained in the samples. Thus designing a sterilization process that successfully protects the sample from contamination, but also does not damage the biosignatures it may contain, is extremely difficult. It is not certain that present sterilization protocols will successfully eliminate contamination risk.

Alteration to Mars environment - 5

This method greatly limits any physical alteration to the Martian landscape and environment, as nature has completed the excavation and no further significant human physical alterations are required, other than the potential removal of small samples. Man-made high velocity impact craters have also been proposed (Baker, 1995) to make craters at desired sites to access the deep Martian subsurface. However, due to the large width of craters required for large depths to be achieved, these man made craters cannot reach as deep as great as natural impact craters, without inconveniently large machinery. Man-made impact craters, however, remove the issue of long term exposure to radiation that natural impact craters possess, but will also cause extremely large human damage to the Martian landscape and potential life.

SCORE: 3.85

Subsurface Cavities/Caves/Lava Tubes
(Léveille, R. J., Datta, S., 2010)

Figure 1. Portion of MO/THEMIS visual image of lava tube collapsed pits, possibly related to flows from Hadriacia Patera.

Overview

On Earth, the natural conduits through which lava travels beneath the surface, or lava tubes, can reach as deep as 2 km. On Mars, lava tubes have been observed, and similar depths could also be reached. Importantly, microbial life has been discovered in these lava tubes or caves on Earth, which also suggests that it is possible for life to be preserved in Martian lava tubes, as they offer a stable, temperature controlled environment, may also contain water, as seen on Earth, and provide protection from radiation and surface weather conditions.

Practical Feasibility

Time to plan and finalize - 3

Underground cave exploration using rovers is limited, although ReachBot, designed in 2018 by Marco Pavone of the Autonomous Systems Lab at Stanford University, was invented to explore Martian caves.

ReachBot still has significant further developments to be made before it can be deployed. As the interior of Martian caves are unfamiliar to scientists, more research into the caves themselves and their physical conditions is required.

Size/practicality of instruments required - 3

The ReachBot is small so robots like it can maneuver through tight spaces, and is light enough to be easily transported to Mars. However, for a robot like this to collect physical samples, it needs additional technologies and mechanisms, potentially making it larger and heavier. Robots can be tested in lava tubes on Earth to develop effective cave exploration and sample collection, although it is not certain that Martian caves will mirror Earth caves.

Maintaining function over changes in physical conditions - 3

Rovers are able to withstand high radiation doses from space. In subsurface caves, there likely exists radiation from radiolytic compounds, but the rover's composition of metals such as titanium protect it from this. Temperatures in the tubes are expected to be constant, and the depths of these caves will protect the robot from harsh winds and dust storms. The major physical changes that pose a challenge are the pressure changes at extreme depths and the uneven surfaces or tight spaces within the cave in which the rover may get stuck.

Operate without direct human intervention - 3

Operating a rover in lava tubes, especially remotely, is very challenging due to the obscured and obstructed path that the radio waves must take to communicate between the rover and surface or orbiters. As a result, it is of high importance that an underground cave-exploring rover must be made autonomous and independent of aid or communication from surface Mars rovers. While this is possible, it will take some time to develop. Having humans on Mars would not necessarily support the functionality of such a rover exploring lava tubes however, as a human may be unable to access the tubes and explore small spaces, for example.

Preservation of sample/ biosignatures - 5

Potential biosignatures in these lava tubes are protected from the exterior conditions of weather, temperature, pressure and radiation from above the surface that are likely to cause harm to biological molecules or signatures. By traveling to the subsurface rather than attempting to unearth it, no new exposure to surface conditions will occur. Samples are also extracted in this protected, stable environment, maintaining their protection. Autonomous analysis or sterilization within the subsurface also enhances the success of finding preserved biosignatures, as bringing samples to the surface exposes it to the harmful conditions stated above.

Planetary Protection

Sterilization/ prevention of backward and forward contamination - 4

It is likely that present sterilization methods can be applied to lava tube exploration with subsurface rovers due to their small size - it is easier to ensure that the robot is fully sterile, in comparison to larger machinery. Its size also limits the mass and volume of samples it can collect, and thus similarly sterilization is more effective. However due to the unfamiliarity of cave conditions to scientists, there may be obstacles, such as the temperature difference between the subsurface and surface, that make the sterilization of samples in transit difficult.

Alteration to Mars environment - 5

As with impact craters, the natural formation of this landform means that no drilling or physical change of the landscape is required. The small size of a rover needed for this subsurface exploration means that it will not cause much physical or erosional harm to the environment by exploring the caves or taking small, shallow samples.

SCORE: 3.80

Inchworm Deep Drilling System

(Rafeek, S. et al. 2001)

Figure 2. CAD Rendering of the Inchworm Deep Drilling System concept. Uses a two part inchworm motion to thrust into ice.

Overview

The Inchworm Deep Drilling System (IDDS) is a subsurface transport system initially designed for Jupiter's moon, Europa, although it has been suggested that this system is applicable to ice on Mars. (Rafeek et al. 2001). It uses an inchworm burrowing method to achieve depths in the order of kilometers. The IDDS drill thrusts into the ground in two parts under its own power, and is able to do so autonomously. Samples can be taken and analysis can be performed at depths, as the system operates independently of gravity.

Practical Feasibility

Time to plan and finalize - 3

The IDDS has been in conversation from as early as the 2000s, so much consideration has been taken into how the IDDS can effectively burrow, as well as the possible in-situ analysis and sample extraction that it can complete. The IDDS was designed initially for ice penetration and so is not certainly effective into the Martian regolith. In ice, however, the IDDS is promising.

Size/practicality of instruments required - 5

The IDDS robot stands at between only 10 and 15 centimeters in diameter and 1 meter in length. It is small, compact and can easily be transported to Mars and carried by a rover.

Maintaining function over changes in physical conditions - 4

The burrowing method is independent of gravity, so the IDDS is able to operate with changes in pressure as it descends. Its metallic composition allows it to withstand radiation, and its narrow, small shape and operation within the subsurface means that weather conditions such as wind are unlikely to affect it. Additional considerations are temperature control and the ability to withstand rocks and minerals that the device may encounter deep below the surface.

Operate without direct human intervention - 5

This robot is autonomous so does not require direct human intervention to operate. The drilling technology, namely an Athena Mini-Corer, requires little power so the IDDS has a high reliability, power density and output duration. Thus humans are not needed to ensure the device is continually powered, and it is likely to be able to operate over depths of several kilometers and over prolonged periods of time.

Preservation of sample/ biosignatures - 5

A great advantage of the IDDS is that it is able to take samples and analyze them from within the subsurface. There is no need for the sample to be removed from the subsurface to determine if biotic signatures exist, and therefore the sample is not exposed to radiation or changes in temperature or pressure that may damage biosignatures. Preservation of samples is more difficult if they must be taken to a rover on the surface of Mars, or back to earth, as the sample is then exposed to harmful exterior conditions.

Planetary Protection

Sterilization/ prevention of backward and forward contamination - 4

As with plasma drilling, the fact that samples are taken from frozen conditions means that sterilizing the samples will be difficult, particularly if higher temperatures are required to complete sterilization. This may be possible with future research, but in situ analysis means that removing the sample from the subsurface and therefore sterilization may not be required.

Alteration to Mars environment - 4

Again, as with plasma drilling, penetrating ice is arguably less harmful than penetrating Martian soil or ground. The IDDS is not very wide so will not create large scars in the landscape. The fact that analysis can be completed within the subsurface means that samples can be left in their initial environment.

SCORE: 4.4

Site Characterization and Analysis Penetrometer System (SCAPS)

(Wesnousky, J. et al. 1996.)

Overview

The Site Characterization and Analysis Penetrometer System (SCAPS) is a real time in-field subsurface screening method, presently used on Earth in the context of petroleum, oil and lubricants. SCAPS was developed with efforts from the Army, Navy and Air Force and has the ability to analyze soil depths as great as 100 feet or more. The cone penetrometer is responsible for physically penetrating the ground. Remote sensors attached to it enable analysis of the subsurface composition. Laser Induced Fluorescence (LIF) and X-Ray Fluorescence analyze petroleum, and thermal desorption and Hydrosparge sensors detect volatile organic compounds. In comparison to the IDDS, SCAPS can be used in the Martian regolith.

Practical Feasibility

Time to plan and finalize - 4

This method is already successful on Earth, used by the Army, Navy and Air Force. Primarily it is used for petroleum, oil and lubricant analysis and detection, so modifications are required for it to detect biological molecules and biosignatures. There also needs to be further consideration around the difference in the Earth's subsurface composition versus that of Mars.

Size/practicality of instruments required - 3

The SCAPS cone penetrometer device used on Earth weighs around 20 tons, 5 times the mass of Curiosity. While it is not impossible to get machinery this large onto Mars, it is more difficult.

Maintaining function over changes in physical conditions - 4

SCAPS is successful in the Earth subsurface conditions, although it has mostly only operated in soil and groundwater environments. Mars is drier than Earth and so the subsurface is likely harder, denser and more difficult to penetrate. SCAPS is able to withstand temperature changes in the subsurface of Earth, but the Martian subsurface is much colder so a temperature control system is important in ensuring the analysis and drilling devices can operate effectively at low temperatures. The heaviness and solidity of this large instrument means that it is likely to be able to withstand pressure changes associated with increasing depth into the subsurface.

Operate without direct human intervention - 2

Again, size is a major inhibiting factor of this device being able to operate autonomously. Presently on Earth, human operation of the penetrometer is required, in terms of choosing a boring location and situating the penetrometer into the ground effectively, although it is not as large and impractical as vertical drilling, for example.

Preservation of sample/ biosignatures - 4

As with the Inchworm Deep Drilling System, SCAPS is able to perform in situ analysis so samples do not need to be taken above the surface to determine if there are biosignatures or organic compounds present at the given site. Thus samples need not be exposed to radiation and exterior surface conditions that harm the preservation of the sample and potential biosignatures it contains. The main concern is using thermal desorption or excitation to identify organic molecules, as presently practiced on Earth using SCAPS. Thermal methods can chemically or physically change and harm biosignatures before or during analysis.

Planetary Protection

Sterilization/ prevention of backward and forward contamination - 4

Again, due to the in situ analysis, samples are not required to be taken out of the ground, thus removing the concern of backward contamination from the samples. The large and heavy nature of the cone penetrometer and the instrument as a whole makes it difficult to completely implement sterilization methods.

Alteration to Mars environment - 3

This method physically creates a permanent excavation scar into the Martian surface. The size of the petrometer means that a large, wide hole is created per borehole location, and it is likely that scientists will intend to look at multiple sites, increasing the physical damage.

SCORE: 3.4

Conclusion

The scores show that of the six methods assessed, the Inchworm Drilling Device System best meets the needs of physical practicality and planetary protection. It is highly successful as it can reach depths of up to several kilometers, is small, lightweight and practical, can operate autonomously and can complete in situ analysis. It creates a direct path from the subsurface to the surface so that communication to rovers and satellites via radio waves is effective and efficient. However, there are further considerations required for the IDDS to be fully successful, including developing the ability to penetrate the Martian soil or regolith rather than merely ice. This will be challenging given that the Martian surface is rough and composed of rocks and minerals, whereas ice is smoother and more uniform and so suits the inchworm mechanism well. More research is required into this and it is not certain that the IDDS will be successful in penetrating the Martian regolith.

Initially, it seemed that natural access methods, such as impact excavation and lava tubes or caves would be most feasible, as they require no physical deep penetration of the surface. The results show that deep mechanical excavation is majorly impractical to depths of several kilometers due the size and weight of equipment required and the need of direct human intervention. These deep drilling methods also severely damage the Martian landscape and are harder to implement sterilization methods on. The natural methods work best in terms of keeping the planet unaltered by human activity. However, impact excavation and cavity exploration also encounter challenges beyond human control, such as the long-term exposure of craters to radiation from space, limited subsurface exploration in caves due to their narrow and undulating structure and communication difficulties with the surface.

While the IDDS is the most promising out of all of the methods examined here, there may be future designs, robots or techniques that are better suited to accessing the deep Martian subsurface in search of evidence of past or present life, while considering physical practicality and planetary protection. However this study also highlights important factors that any proposed mission should include; equipment should be small and lightweight for transport, sterilization and automation purposes. Smaller instruments also create less drastic damage to the planet's surface and landscape. Sites on Mars where large depths naturally occur should be prioritized, as deep drilling, which requires human operation and creates greater physical damage, can be avoided. Operations should be tested in the subsurface of Earth and in replicated Martian conditions on Earth thoroughly. Equipment should be durable for penetrating hard, compact material and maneuvering uneven terrain and potentially tight, uneven spaces. Machinery should be made autonomous and designed to complete extensive in-field analysis so that samples do not need to be brought to the surface or back to Earth, eliminating the risk of backward contamination and the exposure of biosignatures to harmful radiation and surface conditions. Methods should also minimize harm to the physical Martian landscape, so natural access methods should still be considered alongside less harmful penetration methods, such as the IDDS, to maximize the likelihood of successfully searching the deep Martian subsurface for biosignature evidence.

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The Siege of Fort Massachusetts

Sally Neugarten

In North Adams, Massachusetts, a rustic fireplace made of stone stands in the shade of a derelict Price Chopper building, accompanied only by a simple plaque. This fireplace was constructed in 1933 as part of a replica of Fort Massachusetts, a structure that met a similar fate to that of the Price Chopper roughly 250 years earlier. In its heyday, the fort protected the fledgling English colonies dotting the Berkshires as a first line of defense against the French and their Native American allies during King George's War and the French and Indian War. From 1745 to 1760, the fort's valiant soldiers successfully staved off every attack, save for the brutal siege from the 19th to the 20th of August, 1746. Commanded by General Pierre Rigaud de Vaudreuil, 950 French and native soldiers attacked the fort for 27 hours. Those fighting from within, led by Sergeant John Hawks, would surely have continued if it weren't for the near-absolute depletion of their supplies. Vaudreuil recognized the importance of his indigenous allies in successfully defeating the fort; as one Reverend John Norton duly noted in his eyewitness account, the general made multiple major concessions to them as the party, marched into New France immediately following the siege. This paper will discuss in detail the circumstances preceding the siege of Fort Massachusetts in 1746 and delve into the relations between the French and the local indigenous tribes that participated in the attack.

Context

From the earliest days of European colonization, North American land had always been extremely valuable to the settlers, leading to continual conflict. Contending countries, namely the Netherlands, France, and England, were desperate to expand outward and into the others' territories to take advantage of the ample natural resources and to enlarge their empires. The extensive forests were filled with sugar maple, chestnut, and beech trees, and were populated with wolves, martens, white-tailed deer, beavers, and otters, all of which had the potential to become expensive pelts. The skies and waterways abounded with partridge, geese, passenger pigeons, brook trout, shad, and salmon. However, the intensely varied geography directly interfered with the prospect of westward expansion, immobilizing the English in particular. The colonies in Massachusetts were bordered by the Taconic Mountain Range, a subset of the Appalachian Range; the Dutch had beat the English in settling the Hudson Valley while avoiding the treacherous journey across the Taconic by traveling north along the Hudson River, forcing the English to temporarily stagnate development westward, particularly after the settlement of Greenfield in 1686. Simultaneously, the French began expanding along the St. Lawrence River, moving southward and ever closer to New England.

Such were the volatile circumstances upon the outbreak of King George's War, fought from 1744 to 1748. King William's War (1690-1697) and Queen Anne's War (1702-1713) had been fought on New England soil as extensions of European conflicts; King George's War followed suit. This war was a direct corollary of the War of Austrian Succession (1740-1748), in which France, Prussia, and Bavaria exploited the questioned legitimacy of Maria Theresa's succession as ruler of the Hapsburg monarchy as a means to challenge the power structure of Europe. Britain was caught in the convoluted web of European alliances; the Treaty of Vienna, signed in 1727, had firmly bound Britain to Austria. England itself had been fighting the War of Jenkin's Ear (1739-1748) against Spain in the Caribbean, instigated by the constriction of markets in South America as well as by the aforementioned tensions overseas. Spain was allied with France on account of the Pact de Famille most recently reaffirmed in 1743, doubly making France an enemy of England. Further exacerbating the animosity between the two nations were the First (1740-1742) and Second (1744-1745) Silesian Wars, fought by Austria and Prussia over. control of Silesia. Prussia was allied with France, and England with Austria, as previously mentioned After extensive planning, France officially declared war on England in January 1744 with an unsuccessful invasion, kickstarting King George's War in the colonies.

The Native Americans inhabiting the settled land were not sitting passively as these strange men roamed and fought; many tribes formed complicated networks of alliances with one another and with the Europeans and heavily participated in the wars fought on their soil. Throughout the 1600s, the Native Americans of Canada were engaged in the Beaver Wars (1609-1701), in which the Haudenosaunee confederacy [1], comprised of the Mohawk, Oneida, Onondaga, Cayuga, and Seneca tribes, fought with Dutch and English weaponry against the Huron, Erie, Wenro, Ottawa, Petun, Susquehannock, Ojibwe, and Mohican tribes, who were all in turn supplied by the French. In the midst of intermittent warfare, from 1675 to 1678, the Wampanoags, Nipmucks, Podunks, Narragansetts, Nashaway, and the Wabanaki confederacy (Mi'kmaqs, Maliseets, Passamaquoddies and Penobscots) waged war against the New England colonies, Mohicans, Pequots, and the Mohawks in King Philip's War, named after Wampanoag chief Metacom's English alias. Although the New England colonies were victorious, the Wabanaki confederacy regained its strength under an alliance with New France during Queen Anne's War (1702-1713); by 1722, they were sufficiently strong to attack New England during Dummer's War (-1725). The Wabanaki tribes, instigated by the Jesuit priest Father Sébastien Râle—on behalf of French colonial interests—and overlooked during the signing of the treaty of Utrecht in 1713 ending Queen Anne's War, fought to resist English expansion.

Construction of Fort Massachusetts

In light of the constant warfare both in the New World and abroad, Fort Massachusetts was built in 1745 as the westernmost source of protection for the English settlements in Massachusetts. It was the third fort to be built along the frontier of King George's War, preceded by Forts Pelham in Rowe and Shirley in Heath. Colonel John Stoddard, commanding officer of the Hampshire County Militia and in charge of the defense of all of Western Massachusetts, sent a letter on behalf of Massachusetts Governor William Shirley and the General Court to Captain William Williams, head of the militia company in Deerfield, on July 20, 1744. In it, he detailed instructions for the construction of an initial fort—Shirley—as well as "two or three other forts… Erected Each to be about five miles and a Half Distance." Summarized at the top by the memorandum, "The fort 60 feet Square Houses to be shingled the Soldiers Employed to be allowed the Carpenter nine shillings others six shillings a day Old Tenor," the letter also contained an allowance of "Two Hundred pounds old Tenor" for the construction, which was "to be erected about five miles and a half from Hugh Morrison's house in Colrain."[2]

Captain William Williams was once again dispatched by Colonel Stoddard to build Fort Pelham, this time in a letter dated March 6, 1745, "In ten days after this Date to…[finish] a fort in the place where the Comtee for Building a Line of Block Houses &c agreed with Capt. Moses Rice to Build." When Fort Shirley was commissioned, the committee in charge was chaired by Stoddard and otherwise consisted of Oliver Partridge, the high sheriff of Hampshire County and selectman of Hatfield, and John Leonard, a member of a prominent family in Taunton. However, by the time of the release of this letter, Leonard had been replaced by Thomas Ingersoll, a constable and tax collector. This fort that the new committee approved was much less sophisticated than Shirley; instead of a wooden jointed blockhouse, it was merely a palisaded fort consisting of connected posts and staddle stones buried halfway, forming a parallelogram 12 by 24 rods in area. Luckily, its soldiers were never involved in a substantial battle while the fort was active.

Early in King George's War, as these forts were being built, Governor Shirley came to realize that Fort Louisbourg, the strongest French outpost located on Cape Breton Island, had a major flaw and was therefore pregnable. Upon release, English prisoners at the fort had relayed to Shirley that the fortress was in a questionable condition and location, and that mutiny among the French

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[1] The Haudenosaunee Confederacy is more commonly known as the Iriquois; however, many of their enemies, including the Wyandot, were technically also Iriquois, hence this specific name. The Beaver Wars also predate the inclusion of the Tuscarora into the confederacy by 21 years.

[2] Hugh Morrison was a prominent Scotch-Irish farmer and land vendor in possession of 600 acres.

'garrison was imminent. Louisbourg was principally designed for naval assault; as the Canadians never expected visitors from the south, the fort was built on low, level ground and in front of hills, rendering it easily exploitable by land-based forces. With this in mind, Shirley began planning for an eventual siege in January of 1745, recruiting from the best among Massachusetts's military. Notably, joining in the attack was the Hampshire County militia, comprised in part by Captain William Williams, the commander of Fort Shirley, who left in his stead Ephraim Williams, Jr., and Seth Pomeroy, a famous gunsmith who provided an extensive eyewitness account. Armed with a force of 4,300 men, on May 11, one William Pepperell began attacking from the hills as directed by Shirley. After 46 days, the French surrendered their best fort in a resounding victory for the English. For this, Pepperell received knighthood; Shirley, the mastermind behind the battle, was unrewarded.

In fear of retaliation after the successful Louisbourg siege, construction of Fort Massachusetts began in the summer of 1745 in the relatively unexplored region of the northwest corner of the state. The northern border was defined four years earlier by Richard Hazen, a surveyor from Haverhill. He had been commissioned by then-Governor Jonathan Belcher to map out a clear line in response to territorial disputes between New Hampshire and Massachusetts. However, the western border was unclear; Governor Shirley was concerned that Dutch farmers were encroaching beyond the New York border as they expanded outward from the Hudson River. In addition, the ominous presence of Schaghticoke[3] and Abenaki along the Hoosic river bank exacerbated English fears about the ongoing war. When Second Lieutenant John Catlin ventured westward from Fort Shirley, ordered to commence construction of Fort Massachusetts, he must have known its future significance as the primary English stronghold against the French, Dutch, and native inhabitants. The location Catlin chose was approximately one mile away from the intersection of the Ashuwillticook and Mayunsook rivers, now known as the start of the North Branch of the Hoosic River. It was to be far enough from the Hudson Valley, occupied by the Dutch and easily accessible by the French, to not provoke these colonies while also protecting the English as a first line of defense.

Modeled specifically after Shirley, both forts were sturdy affairs encircled by hefty log stockades. Fort Massachusetts measured 120 by 100 feet in area and soared to 12 feet in height. Its walls were 14 inches thick, made of drywall stone and pine timber dovetailed and fastened with pins of red oak. Houses and barracks with sloping saltbox roofs lined the interior of the eastern and southern walls. At the southeast and northwest corners were "great houses" equipped with watchtowers measuring 12 square feet and 7 feet high, ensuring security for the fort's inhabitants. Under the towers, the lower floors of these mounts were reserved for officer's quarters and the storehouse. To the northeast stood a well measuring 49 inches across and 60 feet deep.

As Catlin directed soldiers from Fort Pelham and Shirley in assembling this new fort, he grew wary of the Schaghticokes, Akwesasnes, and Abenakis, who were demanding money in return for the "Great Meadow" underneath. Apparently, Catlin swindled the tribes out of their land. Six years after the fort was completed, on September 3, 1751, Captain Ephraim Williams Jr. reported in a letter to Spencer Phips, the Lieutenant Governor, that:

Last week came to ye fort 8 Scattecook Indians, who told me the land was theirs, and that the English had no Business to Settle it Untill such times as they had purchased of them. They further said yt when we began to Build the first Fort, they told the English they must not Build the Fort Except they would pay them for the land, and that the Commandr had promist them pay, but the English had not been as good as their word.

Williams dismissed their claims as instigation by the French; nevertheless, on January 23, 1752, the Massachusetts House of Representatives voted that Colonel Lydius of Albany and Williams make a "thorough Enquiry respecting the Indian Title to the said lands." Unfortunately, due to the onslaught of the French and Indian War in 1754, the inquiry was shoved to the wayside, and the matter remains inconclusive to this day.

Once the Native Americans demanding compensation were placated with assurances, Catlin focused on stocking up the fort. This was no easy task, as the surrounding lands were unpopulated by the English. There were no roads bridging the mountainous terrain from Fort Massachusetts to Deerfield-which had, until

[3] The Schatighcoke were an amalgamation of Mohican, Oweantinock, Pequot, Pootatuck, and Tunxis peoples.

recently, been the frontier of English settlement—save for the lengthy and equally craggy Mohawk Trail, via which lugging heavy equipment would have been impossible. Flour was particularly hard to drag to the fort; as such, Catlin was advised to negotiate with the Dutch in one of the first substantial interactions between the two colonies. On August 3, 1745, Catlin reported to William Williams that a Mr. Van Ness (spelled in three different ways) offered the fort everything they needed—rum, pork, beef, flour, stockings, and shoes—albeit at an inflated price compared to what Thomas Bardwell of Hatfield and Eleazar Hawks of Deerfield, older brother to the soon-to-be-famous Sergeant John Hawks, were offering. Interestingly, Garret Cornelius Van Ness, the most likely candidate for Mr. Van Ness' identity, had never ventured beyond Albany, connoting that Catlin must have traveled far to secure a trade deal. Despite the difficulties presented by the remote location of the fort, come winter 1745, the fort was sufficiently complete for 43 men to garrison from December 10 to June 9 under the direction of Ephraim Williams.

Forts Shirley and Pelham were in the midst of total peace; however, there were a few skirmishes at Fort Massachusetts during this period. On May 9, 1746, John Mighills and Sergeant John Hawks were fired at by a few Native Americans; Mighills retreated into the fort with a slight injury, whereas Hawks drew his gun and scared the assailants, all the while nursing a substantial wound from which he eventually recovered. On June 11, two days after the recording of the muster-roll of all the soldiers present, Cadenaret, the chieftain of the St. Francis Abenaki, and his men from the village of Becancour on the St. Francis River ambushed the fort. They fatally shot and scalped Elisha Nims and wounded Gershom Hawks, a relation of the aforementioned Hawks. Benjamin Taintor was captured. In response, the soldiers in the fort killed Cadenaret, who was hastily buried with a rope meant to string future English prisoners-of-war together on the return trip to Quebec. According to French records, Cadenaret was actually killed on the 17th during a fight at the Contoocook River in New Hampshire; regardless, the Abenaki were eager to exact revenge on the English in some capacity.

Meanwhile, as King George's War raged on, France was to send its colony massive reinforcement, and England was preparing for a second major attack on New France. Williams was commissioned, along with 1500 other men from Massachusetts, to rendezvous in Albany under Governor Clinton before marching to Montreal. In the interim, Sergeant John Hawks was left in charge of Fort Massachusetts. Clinton operated under the assumption that the King would dispatch a fleet to Louisbourg to participate in his planned amphibious assault; however, before starting northward, the colonists were met with news of the imminent arrival of 40 French ships manned with 3000 men, commanded by Jean-Baptiste Louis Frédéric de La Rochefoucauld de Roye, duc d'Anville. The English plan crumbled under mismanagement and fear of the fleet; however, Williams was still enlisted to join Colonel Joseph Dwight in protecting Boston from this potential naval assault, far away from Fort Massachusetts. Luckily, the French onboard were wholly unprepared for the early September winds, and the offensive shattered; the duke died from grief on September 27 in Halifax, and his successor, Constantin-Louis d'Estourmel, attempted suicide in an act of desperation soon after. In August of 1746, this horrendous failure was still one month in the future; the Canadians were confident enough to engage in warfare in New England to further their cause.

The Siege

By now, Fort Massachusetts was too weak to properly defend itself as the first point of contact with the enemy; the garrison was undermanned and many of the soldiers were sick with dysentery. On August 15th, Reverend John Norton, Dr. Thomas Williams, and 14 reinforcements from Fort Shirley arrived. The next day, Hawks sent Dr. Williams and another 14 men to Fort Deerfield to ask Ephraim Williams, who had recently been stationed there, for supplies and ammunition. This left a total of twenty soldiers to defend the fort, ten of whom were sick. Unbeknownst to these parties, General Rigaud de Vaudreuil had sent eight Schaghticokes and three Frenchmen to scout the fort a few days prior. Vaudreuil had been dispatched earlier in the month by Charles de la Boische, Marquis of Beauharnois, the governor of New France, upon receiving intelligence that the English were poised to seize Fort St. Frederic in Crown Point. However, the Marquis later learned that there was to be no such assault; as such, Vaudreuil headed instead for New England, emboldened by the impending arrival of d'Anville. On August 10th, the Canadians and their Native allies held a council, deciding that the force should attack Fort Massachusetts; 10 days later, they arrived at the Hoosac Valley.

Fortunately, Beauharnois had intricate records kept of even the smallest military campaigns, providing valuable insight into the make-up of Vaudreuil's army. At the River au Chicot, or Wood Creek, a tributary of Lake Champlain in Whitehall, Vaudreuil had combined forces with that of Lieutenant Jacques-Pierre Daneau de Muy, whose unit comprised of "5 ensigns, 6 officers of the militia, 10 cadets, 48 settlers, and about 400 Indians." The Native component consisted of 38 Iroquois of the Five Nations, tribes normally aligned with the English; 69 Outawois of Detroit [Ottawans], "some of whom returned home being unwilling to go to war"; 16 Menominees; 14 Kiskakons of Detroit "who gave proofs of their fidelity to the French"; 4 Sioux; 64 Poutewatamies; 15 Puans; 10 Illinois; 50 Outawois of Michilimakinac, and 40 of the Forks; 65 Mississaguez from Lake Ontario; 80 Algonquins and Nepissings from Lake Nepissing, near Lake Huron; 31 Ojibwe; and 24 Wyandot. To retain the 38 Iroquois, the government supplied the French-Iriquois diplomat Philippe-Thomas Chabert de Joncaire, also known as Nitachinon, with "munitions and presents" for the tribe. Several of the 38 Outawois of Detroit, 17 Ojibwe, 24 Wyandot, and 14 Poutewatamis that arrived on August 22, as listed under de Muy's regiment, initially came from Vaudreuil's initial detachment, complicating efforts to ascertain the exact numbers of the army; however, de Muy ultimately had a total of roughly 470 men. These Native Americans were led by Cadenaret's brother; the council may have picked Fort Massachusetts in part to avenge the great chief's death. This may have united the tribes under a common cause; after all, the Mohawks and Schaghticokes from Vaudreuil were mortal enemies of the Wyandot and Mississaguez of de Muy's cohort.

De Muy was initially ordered to wait at Wood Creek for a fortnight for Vaudreuil's arrival before engaging in warfare in New England. During this time, roughly half of the Native Americans "formed parties and [went] out on excursions," some of them never returning. Vaudreuil had in his command "2 captains, 1 lieutenant, 3 ensigns, 2 chaplains, whereof one is for the Indians, 1 surgeon, 10 cadets of the regulars, 18 militia officers, 3 volunteers, and about 400 colonists and 300 Indians," totaling 740 men. After the rendezvous and the loss of some of de Muy's men, 950 men in all began marching down the Hoosic River, written as Kakekoute in the records. de Muy was left in charge of 30 men and a canoe fleet near Poultney River; the rest continued around Skene Mountain. They then traversed the land of the Mohican chief Keepedo and then that of the Owl Kill trail in the Tiashoke village near the present-day hamlet of Eagle Bridge. At this point, the army split in half, with one brigade put under the management of Sieur de la Volterie on the south bank of the Hoosic and Sieur de Sabrevois on the north. The Native Americans were placed in the front, back, and flanks of the brigades, effectively shielding the French soldiers from bullets and shrapnel. Once divided up, the troops marched 14 miles before encamping on the Cohoha cornfield in North Pownal, leaving 14 more miles for the early hours of Tuesday, August 19.

Early that morning, the French scouts reported to Vaudreuil that a substantial group of English had left the fort, leaving only one sentinel in the watchtower as the vast majority of those inside suffered from dysentery. Upon hearing the news, Vaudreuil was exceedingly confident in a future victory; he galvanized the 950 men, declaring, "My children, the time is near when we must get other meat [in reference to the money they would receive for every prisoner-of-war from Beauharnois upon their arrivals to Quebec] than fresh pork, and we will eat it together."[4] Their spirits high, the men split into their respective brigades upon praying mass and began to march on either side of the Hoosic in the rain. Ten miles later, they all stopped at the River Bend campground, where the council of war agreed for Vaudreuil's force to approach from the forest to the west of the fort, and for de Muy's Native Americans to do so from the river bank to the southeast, armed with scaling ladders and battering-rams. Reverend John Norton wrote in his account—dramatically entitled, "Narrative of the Capture and Burning of Fort Massachusetts by the French and Indians: In the Time of the War of 1744-1749, and the Captivity of All Those Stationed There, to the Number of Thirty Persons... Written at the Time by One of the Captives, the Rev. Mr. John Norton"–that at 9 a.m., the French army surrounded the fort and started firing from the northwest and southeast at the watchtowers. Sergeant Hawks was endowed with the Herculean task of defending the fort with 22 soldiers, roughly half of which were in no condition to fight, and with limited resources; recall that he had sent a party to Deerfield to ask Williams for provisions and reinforcements. The

4 Qtd. in Greylock, p. 137

identities of these men (many of them future founding members of Williamstown) were dutifully recorded by Norton. They valiantly fought until 9 p.m. that day, upon which the French retreated to St. Francis Indian Ledge 60 rods, or 0.2 miles, away.

Just as the English exploited the geography of St. Louisbourg to secure victory, so did the French exploit the strategically disadvantageous position of Fort Massachusetts.. Just to the north, from where Vaudreuil initiated the siege, the elevation of the terrain drastically increased, so much so that the French were easily able to shoot over the walls and into the fort. Vaudreuil gained the upper hand by 11 a.m. the next day. He had his men raise a flag of truce and offered Hawks an opportunity to surrender. Else, Vaudreuil would burn the fort to the ground. After a quick analysis of the supplies left—with what they "did not judge to be above three or four pounds of powder and not more lead," they could have lasted only "a few minutes" more–Hawks and Norton agreed to relinquish the fort. "Had we all been in health, or had there been only those eight of us that were in health, I believe every man would willingly have stood it out to the last," Norton regretfully wrote. "For my part I should; but we feared, that if we were taken by violence, the sick, the wounded, and the women, would most, if not all of them, die by the hands of the savages." The French successfully captured the fort by 2 p.m. The victors hoisted a flag prominently displaying the fleur-de-lis atop the watchtower to the northwest, and the Jesuit chaplain let the banner of the Holy Cross unfurl over the southeast tower. Norton placed a "Notice of the Surrender of Fort Massachusetts" on the burned well sweep for Dr. Thomas Williams to find, which read:

These are to inform you that yesterday, about nine of the clock, we were besieged by, as they say, seven hundred French and Indians. They have wounded two men and killed one Knowlton. The General de Vaudreuil desired capitulations, and we were so distressed that we complied with his terms. We are the French's prisoners, and have it under the General's hand, that every man, woman, and child shall be exchanged for French prisoners.[5]

Soon after, the 29 men, women, and children of Fort Massachusetts embarked on their journey to Montreal, where they arrived on September 25th under these terms of imprisonment, as Norton recorded:

I. That we should all be prisoners to the French; the General promising that the savages should have nothing to do with any of us.

II. That the children should all live with their parents during the time of their captivity.

III. That we should all have the privileges of being exchanged the first opportunity that presented.

Besides these particulars, the General promised that all the prisoners should have all Christian care and charity exercised towards them; that those who were weak and unable to travel should be carried in their journey; that we should all be allowed to keep our clothing; and that we might leave a few lines to inform our friends what was become of us. In comparing these terms and Norton's account of the entirety of his imprisonment with the experiences of other prisoners-of-war, like those from the Raid on Deerfield in 1704, for example, one must assume that the party was treated quite nicely. Those who could not keep up on the way to Quebec from the Deerfield massacre were killed; conversely, Josiah Reed, one of the sick soldiers captured during the Siege, was carried on the back of a Native American.

The siege left in its wake tragic repercussions. Ultimately, two people died: Cadenaret's brother, shot by Hawks, and Thomas Knowlton, the sole watchguard. He was scalped and an arm and leg were taken from him as a war prize. 12 of the French were wounded, including Vaudreuil, who was shot in the arm; John Aldrich and Jonathan Bridgeman were injured as well, the latter dying en route. There was more destruction to come. Vaudreuil sent 60 Abenaki and Iroquois to meet the returning party, consisting of 19 men. Not having met them, on August 25th, the Native Americans instead killed seven in Deerfield South Meadow—Samuel Allen's child, Eleazer Hawks (the sergeant's nephew), Oliver Amsden, Simeon Amsden, Constant Bliss, and Adonijah Gillet–in what is now known as the Bars[6] Fight and immortalized in a poem by Lucy

[5] Qtd. in Perry, p. 142

[6] Bars was a colonial term meaning "meadow."

Terry, a slave from Rhode Island, making it the first known work of literature by an African American. The Native Americans brought back Samuel Allen and one Black man as prisoners. In addition, 17 Mississaguez from de Muy's detachment who had left before besieging Fort Massachusetts had returned to Vaudreuil with 4 scalps; Norton saw them as well as those from the victims of the Bars Fight on August 31.

By the evening of August 20, all that was left of Fort Massachusetts was the note Norton left and a mess of rubble, smoke, and ash. The fort lay in ruin until the winter of 1747, when it was rebuilt after Governor Shirley sent a letter on April 10, 1747, to John Stoddard, authorizing him to "erect and build a good commodious Blockhouse at or near the place where the Fort called Massachusetts late stood." This new fort defended the colony of Massachusetts throughout the remainder of King George's War, which was completed with the signing of the treaty of Aix-la-Chapelle in 1748, and until the end of the French and Indian War in 1763. As the years progressed, the fort fell into disrepair, and parts were repurposed for the building of houses throughout the region. Thus concludes the history of the siege of Fort Massachusetts, save for that of Native American involvement.

Indigenous Involvement

The staggering diversity of tribes participating in the siege was indicative of the complex history between the French and the Native Americans. To conduct a complete analysis, one must travel back in time to the end of the Beaver Wars in 1701, after which the Great Peace of Montreal was signed, as organized by Louis-Hector de Callière, governor of New France. Signed treaties between colonial powers and tribes were exceedingly rare since most alliances were informal and were made for primarily commercial benefit. Often, amicable relationships were established between the French and tribes upon the first instance of prolonged contact, most of which occurred throughout the 17th century. However, analyzing the signers of this treaty yields a nearly complete picture of the indigenous peoples connected to the French.

Although King William's War, a theater of the Nine Year's War–fought between France and the Grand Alliance (Holy Roman Empire, the Dutch Republic, England, Spain, and Savoy)–had officially ended with the ratification of the Treaty of Ryswick in 1697, the question of with which European power the Haudenosaunee were allied had remained unresolved. Tribes allied with the French continued to conduct sporadic attacks on those within the confederacy, yet both the English and French claimed Iroquois land as within their respective empires. Preliminary agreements ceding prisoners to the French and land to the English were reached on September 3rd of the preceding year in Onondaga, where the village of Manlius, New York is currently located, and on July 19, 1701, as part of Nanfan's Treaty. However, the French wanted to expand their influence by placating previous animosities between the Haudenosaunee and enemy tribes. 38 tribes signed the Great Peace treaty, including, most pertinently, the Abenaki (as a proxy for the Wabanaki Confederacy), Ottawa, Algonquin; Mississaguez, Nipissing, Poutewatamie, Miami,nMenominee, and all those belonging to the confederacies of the Haudenosaunee and the Illinois (Kaskaskia, Peoria, Tamaroa, Maroa, Coiracoentantanons, and Moingwena). While overseeing the delegations, Callière smoked and passed a Calumet of Peace presented to him by the Miamis. Of the motley of tribes that participated in the Fort Massachusetts siege, all but the Sioux, Wyandot, and Schaghticokes, all informally aligned with the French through trade or during future wars, were present. The Sioux had been collaborating with the French since 1660 when fur traders Médard Chouart des Groseilliers and Pierre-Esprit Radisson first explored parts of Wisconsin. Earlier, Jesuit missionaries had encountered the Wyandot as early as 1639, as noted by François du Peron in the Jesuit Relations chronicles. The Schatighcoke were initially allied with the English but shifted towards the French after the Governor of New France supplied them with ammunition during Dummer's War. All of these tribes had previously had idiosyncratic connections to one another and the French, but this was the first time they were all assembled in a political settlement of this magnitude.

Prior to the Beaver Wars, the Haudenosaunee controlled a huge swath of land across what is now the northeastern part of the United States and southeastern Canada, pushing other tribes further west and into contact with the French. The Beaver Wars united these tribes under the umbrella of French protection; during this conflict, many were introduced to European weaponry for the first time. Once the Iriquois collaborated with the French to sign the Great Peace of Montreal, Callière was placed in an optimal position. Although not all the signers were allie with the French against the English—the Haudenosaunee

Confederacy often sided with the British—this promise of peace secured for New France the opportunity to recruit warriors for future battles, including those fought during King William's War in New England.

Alliances with native inhabitants of America were exploited throughout early colonial history as a means to conquer competing European settlements. The roughly 950 Native Americans that accompanied Vaudreuil when he marched into the Hoosac Valley in August 1746 were present on account of an extensive list of tribe and confederacy-specific treaties and negotiations previously made by the French. Eventually, the English and French embroiled themselves in the French and Indian War (1754-1763), a corollary of the Seven Year's War (1756-1763), resulting in the removal of the French from North America. As the English expanded into the French territory and further westward, the tribes that had once participated in European wars were either exiled or forcefully assimilated into the settlers' culture, permanently staining the history between the Native Americans and the modern United States.

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Third World Women: Recontextualizing the Feminist Movement

Jazmin Morenzi

In 1972, a coalition of Black, Raza, Indian, and Asian women created a collection of poems, essays, and artwork called Third World Women. This anthology, along with several others published by the same company, highlights the voices of women of color in the feminist movement. The editors of the San Francisco-based publishing company, Third World Communications, noted that they wanted to “reflect the struggles of Third World women” and the “outcomes of [their] comin’/workin’/learnin’/growin’ together” (n.p.). While the anthology includes an even distribution of literary and artistic content throughout its 185 pages, I explore two poems: First, in her poem “The Black Latin & the Mexican Indian,” Avotcja explores her personal struggles as a minority living in America. Second, “My Son, My Daughters,” by Dorinda Moreno G., illustrates the shame instilled in people of color, describing how their native religion, language, and tradition no longer uniquely or singularly belonged to them. The assemblage accomplishes the ultimate goal of the anthology: reclaiming the term “Third World Woman.” Its content guides readers toward recontextualizing life for women of color by creating spaces for critical thought and emotional expression. This combination of art and analysis ultimately supports the expansion of the feminist agenda and reclamation of power for women of color to encourage a globalized consciousness-raising culture.

The editors of Third World Women use the term “Third World” strategically to reclaim this derogatory term as a phrase of solidarity. As a Cold War term, “third world” refers to “underdeveloped or poorer countries of the world, usually those of Africa, Asia, and Latin America” (OED). In her book Remaking Black Power, Ashley Farmer explains that in the eyes of the “First World,” the places where “Third World majorities” come from are desolate places devoid of quality of life or culture (Farmer 161). By placing the phrase on the cover of the anthology in large, bold text, the editors claim ownership of it and propel the multidimensionality of women of color. Erica E. Townsend-Bell acknowledges in her article “Writing the Way to Feminism” that “Third World (colonized) women [were] becoming more aware of their oppression in the past” (Townsend-Bell 138). During their writing process, the editors practiced open and empathetic dialogue, thus exemplifying their goal of helping women find solidarity in the anthology.

During the late 1960s and early 1970s, feminists sought to link the social injustices against women of color to anti-imperialism through artistic expression and poetic lyrics. Avotcja’s poem “The Black Latin & The Mexican Indian” depicts the loneliness of living in America as a minority at the beginning of her poem. Her loneliness comes from an imposed and imperialistic obligation to serve white people, as she narrates that she “[works] for pennies — so that white ladies could / wear silk stockings” (133). Her profound isolation is alleviated when she introduces another person into the narrative. She seeks solidarity in her struggle when she asks her new friend, “[w]ere you lonely too? (133).” The narrator goes on to describe an almost cathartic friendship that develops between her and her new companion, evoked by their shared experience as survivors and victims of necessity: “While you picked tomatoes / I picked pockets

And we both learned how to lie and steal and fight / Some call it survival / I call it loneliness” (133). She marks the end of her solitude when she transitions from the usage of “I” to “we” with the introduction of another person with similar oppression. The physical presence of another helps her realize her strength and sense of community: “But, one day the smog lifted / The city and the country smiled at each other / And so did we” (133). By relating the experience of a Mexican person to an Indian person, Avotcja emphasizes the unity and strength that comes from realizing a shared oppression. Third World Communications uses the message in Avotja’s work to encourage women of all demographics to converge and fight their common struggles.

The poems, art, political commentary, and stories shared in Third World Women reflect the "commonalities of oppression among women of color" and encourage the collaboration of women and people of color within the Liberation Movement (Farmer 160). "My Son, My Daughters" by Dorinda Moreno G. illustrates traits of a driving force within the movement. First, she sets the scene in which "power relationships are as palpable as tangible locale," and establishes her heritage and location in "las montañas de Nuevo Méjico" (Voyce 188). Setting the scene outside of the U.S. and recounting atrocities that white people have committed highlights an imperialist pattern in America's behavior. Moreno hints at the past richness of her community stripped away by "a people whose military strength overpowered [theirs]," emphasizing white imperialists' continued tendency to spread rigid ideals to communities that do not welcome them (70). Moreno states in the first stanza that she is Chicana and the "daughter of many farmers before [her]," which contributes to awareness of a stereotypical role among Chicano people living in America (70). This advances the power dynamic between the more powerful white America and the Chicano people through an emphasis on the systematically unjust pattern of low-income work prevalent in communities of color. Moreno's usage of "we" implies a transition in her poem's message; she strives to address a common opposition by building community and raising consciousness about the history of her people. Furthermore, the narrator implies the passage of struggle to future generations, her son and daughters, emphasizing the imminent recurrence of such oppression. Moreno globalizes the movement by expanding the conversation across borders, recounting the stories of Chicano people and emphasizing the connection between Mexican people living in America versus those living in Mexico: "I am Chicana / My thoughts are still that of my ancestors" (70). Despite her oppression, she denotes her confidence in the future generations to open a path and be "rich in reverence and respect" (70).

Photography, illustrations, etchings, and more are paired with literature throughout the anthology to refute the villainization that people of color face. Additionally, the vulnerability, rawness, and expression within the compilation of art directs the readers toward recognizing the diverse nature of the movement. For example, "Tristeza, laberinto y sueno" (Sadness, Laberynth, and Dream), an etching by Consuelo Mendez, illustrates the isolation and dehumanization that ensues from being a woman of color in a patriarchal society (24). The etching, accompanied by a series of two poems by Ena Hernandez, features a naked woman standing in a dark void, gazing at the ground on which her straight hair slithers. Her limbs are cartoonishly long, her head is too small, and her stomach is bloated, implying a pregnancy. This caricaturing of the woman is representative of social bias toward white beauty standards and a dehumanizing view of women of color who cannot fulfill them. The poems beside it detail a court case in which Child Protective Services takes away a Black mother's children. She is "accused of being an unfit mother," but she fights back, explaining "the energy / it takes, the energy that love provides," but the jury does not listen and takes her children away (25). The dark void surrounding the woman in the etching represents the shrowding grief and loneliness the mother feels. Despite her efforts to become accustomed to the "assimilation!" and "[d]ehumanization!" she is left alone in a country where political and social power is given to white people (25). Her grotesque depiction in the illustration displays how Black women are viewed in America. Black women tried to assimilate into white culture, using skin-bleaching products and hot combs: "Kinky hair Is ugly straight hair is beautiful" (25). However, no matter how compliant they are to the jurisdiction of white America, Black women are seen as inferior; the pairing of art and poetry combat the falsity of this notion.

Anthologies drove the intersectional context of the Liberation Movement of the 1970s. Because of the overwhelming whiteness of the period, the feminist movement often excluded the voices of women of color. The anthology Third World Women broke the barrier between a race-centered human rights movement and the feminist liberation movement by implementing an intersectional consciousness-raising approach to feminism. By using the idea of the "common woman," the editors of Third World Women utilize the artistic and scholarly talents of women across the nation to provide an anti-imperialist framework for feminist liberation. The anthology's beauty comes from the many ways that poetry is presented; the editors inserted poems in their original languages and included a translation into English beside them. This preserved the raw expression and original message within the poetry, which stresses that art is language-less and does not require a deep structural understanding of grammar and syntax. The editors agreed that “works should reflect Third World consciousness, that it should relate to the realities of what is happening in our respective communities,” opting to “redefine the criterion of art, literature, poetry, and political analysis” (n.p.). This recontextualization of the art created by women of color resulted in a collective shift in how women in the liberation movement collaborated. The editors of Third World Women used the power of artistic expression to their advantage to raise public awareness of the daily and lifelong injustices and atrocities committed against women of color.

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Sustainable Retirement Investments: Shifting Paradigms at Williams College

Diliara Sadykova

Abstract
This paper presents a comprehensive analysis and strategic plan for integrating Environmental, Social, and Governance (ESG) retirement funds into Williams College's retirement investment options. It begins with an exploration of the non-monetary benefits of ESG funds, particularly in relation to addressing climate change. Subsequently, it examines Williams College's commitment to sustainability and highlights the strategic alignment of ESG funds with institutional goals. Statistical analyses, utilizing both national and college-level performance data, underscore the financial viability and resilience of ESG funds. Additionally, a parallel analysis of ESG funds from other US colleges reveals compelling options with strong relative annual performance and stable volatility levels. The paper concludes with recommendations for engagement and implementation strategies, communication plans, and proposals for collaboration and expansion, emphasizing the pivotal role of sustainable retirement investments in advancing institutional sustainability goals and combating climate change.

Introduction

Sustainable investing (also known as "socially responsible investing" and "impact investing"), emphasizing environmental, social, and governance (ESG) considerations, has been gaining ground among investors over the past decade. The global assets committed to sustainable investments reached $35.3 trillion in 2020, a 15% increase from 2018,[1] reflecting a growing interest in aligning investment decisions with ethical values and long-term sustainability goals. More recently, ESG funds have become heavily politicized in the U.S. and been criticized globally as greenwashing and for a lack of transparent, comparable performance data.

Distinguishing sustainable investment from conventional approaches lies in the selection of assets for portfolio construction. Stocks in sustainable funds adhere to various ESG prescriptions and ethical guidelines, catering to personal and political beliefs. Both individual and institutional investors are progressively attuned to ESG issues, prompting the investment community to adapt. The evolution of sustainable investment includes ethical, impact, and socially responsible investment varieties, supported by international efforts such as the United Nations Principles for Responsible Investment (UN PRI) and the Social Investment Forum.

The relevance of sustainable investment becomes pronounced in the context of retirement investing, particularly for institutional investors like pension funds and individuals with retirement accounts. With investment horizons spanning several decades, retirement investments cause long-term consequences, such as effects on climate risk. Balancing sustainable, long-term returns with investment risk management is crucial for retirement portfolios.

Global interest in sustainable investing continues to surge, with nearly $2 trillion invested globally in sustainable funds. The first quarter of 2021 witnessed a doubling of net inflows to sustainable funds in the United States.[2] The demand reflects organizations' desire to align investment processes with their values, as highlighted in a survey where 57% of institutional investors cited alignment with organizational

[1] Capital Partners. "The Rise of Sustainable Investing." 2023. https://www.lcrcapital.com/blog/rise-of-sustainable-investing/#:~:text=According%20to%20a%20report%20by,a%2015 %25%20increase%20from%202018

[2] Jessop, S., Murugaboopathy, P.. "Sustainable fund inflows hit record high in Q1: Morningstar." 2021. https://www.reuters.com/business/sustainable-business/sustainable-fund-inflows-hit-record-high-q1-morningstar-2021-0 4-30/

values as a primary motive for ESG strategies.[3] The performance of sustainable funds further supports their attractiveness, with consistent outperformance in seven of the last ten years and an average growth of 4.6% compared to 1.1% in the first quarter of 2021. This paper aims to motivate Williams College to introduce more options of sustainable retirement funds/bonds by presenting a qualitative analysis of the College's retirement investing impact on its carbon footprint and alignment with sustainability plans. Additionally, an extensive quantitative examination of eight years of mutual funds/bonds performance data from Teachers Insurance and Annuity Association of America (TIAA) aims to discern any performance differences between ESG funds and conventional counterparts.

This study addresses key questions regarding sustainable retirement investing at Williams:

1. What are the non-monetary benefits of sustainable assets?
Analyzing contemporary trends in climate action and its intricate relationship with environmental and social justice is essential for comprehending the rationale behind incorporating green investment options. Furthermore, this investigation will consider the interplay between the drive for achieving zero net emissions and its alignment with the strategic plans of Williams College.

2. Does sustainable retirement investing entail a tradeoff in performance?
This question is answered by analyzing the performance of both conventional and sustainable funds currently offered at Williams, expanding the scope to include additional green funds available at other US Colleges.

3. Do sustainable retirement funds carry more risk than conventional funds?
This inquiry involves an analysis of variance among funds, considering performance metrics and focusing on the coefficient of variance.

Terminology Note: to streamline the discussion in this paper, it's important to note that terms such as responsible investment, impact, green, sustainable, and ESG investment, as well as funds and bonds associated with these concepts, will be used interchangeably. While recognizing that each term may have nuanced differences, for the purpose of this paper, we consider them as part of a broader landscape without delving into specific distinctions.

Literature Review

What are the non-monetary benefits of sustainable assets?

The 2015 Paris Agreement marked a pivotal moment when governments globally acknowledged the imperative for immediate action to combat climate change, recognizing its potential catastrophic consequences on both humanity and the planet. Unsustainable business practices, leading to deforestation, biodiversity loss, and the degradation of ecosystems, contribute to the deterioration of natural capital—comprising air, water, soils, forests, plants, and animals.

Existing literature generally suggests that sustainable investments, particularly Environmental, Social, and Governance (ESG) funds, do not adversely impact financial outcomes for pension investors in comparison to conventional investments. However, a significant gap in these studies pertains to the lack of consideration for institutional investors like colleges, with notable examples like TIAA. This paper aims to build on existing literature by addressing this specific institutional perspective.

Literature on Climate Change Analysis

The literature consistently underscores the urgent need for immediate and substantial action in response to the escalating climate crisis. Climate scientists unequivocally warn of the potentially catastrophic consequences resulting from the significant human-induced production of greenhouse gasses, leading to disruptions such as heatwaves, wildfires, droughts, famines, flooding, melting ice, sea-level rise, mass migration, pandemics, and war.

The global mean atmospheric temperature has already increased by approximately 1.0°C since the Industrial Revolution, causing tangible harm and presenting substantial risks to human well-being and the

[3] Natixis Investment Managers. "ESG Investing Survey Insight Report." 2021. https://www.im.natixis.com/sg/research/esg-investing-survey-insight-report

environment.[4] The Paris Agreement, a landmark international accord signed by 195 nations, commits to limiting global temperature increases to well below 2°C above pre-industrial levels and pursuing efforts to cap the increase at 1.5°C.[5] Achieving these targets requires significant reductions of 25% in greenhouse gas emissions by 2030 and net-zero emissions by 2050 or 2070, depending on the temperature goal.[6]

However, the current trajectory, if left unchecked, could result in a devastating increase in global mean temperature (by 3.7°- 4.8°C by 2100), far exceeding the limits set by the Paris Agreement.[7] This alarming scenario underscores the critical need for comprehensive risk assessment, adaptation, and mitigation efforts to address the severe consequences of climate disruption.

Building upon the discourse on climate justice and social protection, climate change presents immediate and escalating risks to communities, affecting aspects such as health, safety, quality of life, and economic growth, with vulnerable communities experiencing the most profound impact. Moreover, the rising frequency of zoonotic virus outbreaks, as illustrated by the 2020 COVID-19 pandemic, is intricately connected to climate change, as it exaggerates the pandemics by causing the migration of virus carriers, introducing supplementary threats to global health. It is well-documented that communities residing in marginalized areas bear the brunt of these challenges.

Additionally, the literature highlights the inadequacy of relying solely on national and international regulatory efforts and climate pledges to effectively address the global climate challenge.[8] Therefore, this paper aims to foster a more active involvement of private institutional organizations in contributing to climate action.

Climate justice revolves around the ethical imperative of addressing the disproportionate impacts of climate change on marginalized and disadvantaged communities. It emphasizes the need for fair and inclusive policies and interventions that prioritize the well-being of those most vulnerable. By recognizing the interconnectedness of climate change, health crises, and social disparities, society can foster a more *inclusive, sustainable, and resilient future.*

Importance of Adding ESG Funds

In light of this scientific reality, recognizing the pressing importance of addressing climate change, it is essential to consider financial strategies aligned with Environmental, Social, and Governance (ESG) principles. The urgency of the situation requires a reevaluation of personal investment portfolios, especially retirement funds, to align them with values that favor a reduction in greenhouse gas emissions and support innovative business solutions to the climate challenge.

ESG funds provide an avenue for individuals to contribute positively to the global climate challenge. By prioritizing investments in companies with strong environmental practices, social responsibility, and effective governance, individuals can actively participate in the transition to a sustainable and climate-resilient future.

This additional structural point emphasizes the role of responsible investing in addressing the climate emergency, highlighting that individual actions, such as aligning personal retirement investments with ESG principles, can contribute to the broader global efforts needed to mitigate climate change. The integration of ESG funds into investment portfolios becomes not only a financial strategy but also a conscientious response to the urgency outlined in the scientific literature above.

Analysis of the UPenn's study and Implications for Williams College

The recent research from the University of Pennsylvania (UPenn) sheds light on critical aspects of

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4 Climate Analytics. "Global Warming Reaches 1°C Above Pre-industrial: Warmest in More Than 11,000 Years." https://climateanalytics.org/briefings/global-warming-reaches-1c-abovepreindustrial-warmest-in-more-than-11000-year s/

5 United Nations Framework Convention on Climate Change (UNFCCC). "The Paris Agreement." https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

6 Intergovernmental Panel on Climate Change (IPCC). "Special Report: Global Warming of 1.5 ºC." 2019. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

7 Pachauri, R., Meyer L. Intergovernmental Panel on Climate Change (IPCC). "Climate Change 2014: Synthesis Report." 2014. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf 8Orts, E. "Climate Contracts." 2010. http://www.velj.org/climate-contracts.html

8 Orts, E. "Climate Contracts." 2010. http://www.velj.org/climate-contracts.html

the current state of sustainable retirement investment at the US Colleges.[9] The revelation that TIAA, the exclusive service provider for UPenn's faculty retirement plans, has a substantial $78 billion in fossil fuel investments serves as a stark reminder of the potential environmental impact embedded in retirement portfolios. Williams College should recognize the magnitude of this revelation as it prompts a thorough examination of its own investment strategies.

Faculty awareness at UPenn emerges as a notable concern, echoing the potential lack of knowledge within Williams College's community regarding the climate impact of retirement investment options. The parallels between the institutions underscore the importance of transparent communication and proactive efforts to ensure faculty members are well-informed. Faculty advocacy takes center stage in UPenn's case, where 299 individuals submitted a complaint to the Principles for Responsible Investment, reflecting a growing trend of activism. This proactive approach contributes to a more environmentally conscious investment landscape. Establishing channels for open dialogue and educational initiatives can cultivate a sense of responsibility among faculty at Williams College as well.

An alarming finding from the UPenn research is the potential discrepancy in funds labeled as "social choice" or "low carbon," which may have higher rates of fossil fuel investment. Williams College must scrutinize the composition and performance of its future socially responsible investment options to ensure they genuinely align with environmental goals, providing faculty with meaningful choices that resonate with their values.

One of the most remarkable findings from the UPenn study is a graphic attached to the resolution, which estimates that faculty and staff retirement funds contribute to approximately 2,470,320 metric tons of carbon dioxide annually. This staggering figure *surpasses the greenhouse gas (GHG) emissions from campus operations by several times*, despite these operations being the primary focus of sustainability measures and included in the scope 1 and 2 GHG emissions accounting.

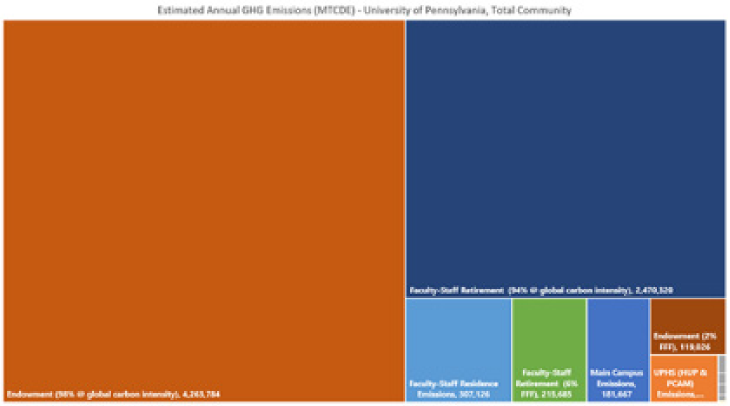

Fig.1. Distribution of sources of GHG emissions[10]

The significance of this disparity and the impact of greenhouse gas emissions from retirement investments, in comparison to those from residence, campus operations, and other sources, are alarming. Remarkably, there is a lack of concerted efforts to address and reduce these emissions. The carbon dioxide emissions from retirement investments fall under Scope 3 emissions, a category not currently captured at Williams College. Therefore, the estimations from UPenn provide the closest (as for now) insight into the relative contribution of Williams College's retirement investments to the overall carbon footprint.

This revelation presents a compelling argument for the urgent implementation of more sustainable retirement investment options. Recognizing and addressing this aspect of carbon emissions becomes crucial for institutions like Williams College to align their investments with sustainability goals and actively contribute to reducing their overall environmental impact.

In summary, the UPenn research underscores the urgency for Williams College to critically evaluate its retirement investment strategies. By learning from UPenn's experiences, Williams College can enhance transparency, engage with faculty concerns, and strive for a more sustainable and responsible approach to retirement planning. The contradiction highlighted by UPenn faculty, where earnings contribute to destroying the future they aim to nurture,

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[9] Castiglione, E. University of Pennsylvania. "Retirement funds for Penn faculty managed by company with billions in fossil fuel investments." 2023. https://www.thedp.com/article/2023/02/penn-faculty-retirement-tiaa-fossil-fuel-investments

[10] Castiglione, E. University of Pennsylvania. "Retirement funds for Penn faculty managed by company with billions in fossil fuel investments." 2023. https://www.thedp.com/article/2023/02/penn-faculty-retirement-tiaa-fossil-fuel-investments

should serve as a compelling call to action for Williams College to align its investments with its commitment to environmental stewardship.

Analysis of Williams College's strategy plans.

***Strategic Plan*[11]**

1. Sustained Commitment to Sustainability

From the plan:

"Williams is committed to the responsible stewardship of its campus environment and recognizes that our actions have impacts beyond its borders. Our commitment to sustainability starts with the recognition that climate change and environmental degradation are defining challenges of our time…"

Incorporating ESG retirement funds aligns with Williams College's sustained commitment to sustainability. By providing faculty members with the opportunity to invest in environmentally-conscious options, the College reinforces its dedication to addressing climate change, fostering responsible resource use, and promoting social justice. Introducing ESG retirement funds provides a tangible means for faculty members to actively participate in this mission. By selecting investments aligned with climate-focused initiatives, faculty contributions to retirement portfolios become a direct extension of the college's broader efforts to mitigate its carbon footprint and work towards a sustainable, low-emission future.

2. Educational and Research Impact:

ESG retirement funds contribute to the college's commitment to education and research in sustainability. By engaging faculty in these investment choices, Williams College creates a living laboratory for exploring the intersection of finance, environmental impact, and social responsibility. This educational component not only enhances the faculty's financial literacy but also aligns with the broader goals of the institution in teaching and research. Therefore, as a part of the implementing the ESG investment options, we are advocating for adding the educational website on the importance of sustainable investing.

3. Community Collaboration and Social Equity

From the plan:

"Collaborating with other colleges and universities to increase impact"

"Making clear connections between our environmental actions and social justice"

Being in touch with Amherst College and in the future with other US Colleges emphasizes the importance of collaboration considering the interconnectedness of environmental actions and social justice. Faculty members across all US Colleges, through their investment choices, become integral partners in advancing community-wide sustainability goals, fostering a sense of shared responsibility. Moreover, the crosscutting commitments to Diversity, Equity, Inclusion, and Accessibility (DEI) and Sustainability are woven into Williams College's strategic plan. ESG retirement funds contribute to these commitments by promoting responsible investment practices.

***Investment Office Strategy*[12]**

1. Fossil Fuel Phase-Out

President Mandel, in April 2022, communicated the Investment Committee's commitment to gradually phase out investments in fossil fuel projects within commingled investment funds.

The addition of ESG Retirement Funds aligns seamlessly with the commitment to fossil fuel phase-out and prioritizing impact investments. It reflects a continuation of the Investment Office's dedication to investments that not only generate financial returns but also contribute to broader environmental and social goals.

2. Demonstrating Leadership

The commitment to cease new investments in oil and gas extraction projects, announced in 2021, positions the college as a leader in sustainable investing. The addition of ESG Retirement Funds further solidifies this leadership, showcasing a forward-thinking approach and dedication to positive environmental and social impact.

3. Diversification of Sustainable Investments

The Investment Office, charged in 2015, exceeded

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11 Williams College. "Strategic Plan 2021." https://www.williams.edu/strategic-planning/strategic-plan-2021/

12 Williams College. "Investment Office's strategy." https://investment.williams.edu/about/investment-strategy/

the mandate to allocate $25 million in endowment funds to investment managers specializing in reducing global greenhouse gas emissions. With a commitment of $30 million by FY2020, the endowment has deployed $50 million across six funds, achieving the dual objective of financial returns and measurable reductions in greenhouse gas emissions.

Integrating ESG Retirement Funds allows for a diversification of investments within the broader portfolio. This diversification is in line with the College's strategy of seeking opportunities in alternative energy and environmentally responsible ventures.

***Climate Action Plan*[13]**

The introduction of ESG retirement funds at Williams College aligns with the institution's climate plan objectives. The goal of achieving a 35% reduction in net greenhouse gas emissions by 2020 emphasizes a holistic approach to sustainability, and ESG retirement funds become a crucial instrument in involving faculty members directly in this initiative.

1. Endowment Investments for Environmental Benefit

From the plan:

"Action 6: Continue investing the endowment in impact investments that promote measurable reductions in global carbon emissions"

Williams College's commitment to investing the endowment in projects benefiting the environment includes significant financial commitments to alternative energy projects. The introduction of ESG retirement funds not only complements these existing efforts but also extends the opportunity for faculty to contribute actively to projects that align with the College's environmental goals.

2. Alignment with Educational Mission

The strategic investments in the College's educational mission, such as faculty positions focusing on climate change, underscore a commitment to integrating sustainability ESG retirement funds further reinforce this commitment by providing faculty members with an avenue to translate their financial choices into tangible contributions to the campus-wide theme of inquiry into anthropogenic climate change.

3. Scope of GHG Accounting and Voluntary Scope 3 Actions

The acknowledgment that GHG accounting does not include investments highlights the need for complementary actions. Introducing ESG retirement funds becomes an integral step in addressing the voluntary Scope 3 emissions by allowing faculty to make environmentally conscious investment decisions, filling a critical gap in the overall climate strategy.

In summary, the addition of ESG retirement funds at Williams College becomes an integral component of the institution's broader strategic and climate plan. It not only addresses specific goals related to greenhouse gas emissions but also empowers faculty members to actively contribute to the college's sustainability objectives. The strategic alignment with ongoing initiatives, commitment to impact investments, and the phasing out of fossil fuel projects all highlight the synergies that can be achieved by introducing ESG retirement options.

Statistical Analysis of Performance and Variance of Williams College's retirement investment options

National scope: USA

Until recently, there has been a common misperception among decision makers and plan sponsors that selecting ESG funds for inclusion in retirement plans risked sacrificing investment performance relative to other mutual funds.

There have been over 2,000 studies designed to understand the relationship between ESG criteria and corporate financial performance. Based on a review by Sustainable Finance and Investment research, "90% of all studies showed a non-negative relationship, indicating that the inclusion of ESG factors did not affect performance. In fact, the majority of the studies reported a positive relationship, indicating that ESG criteria improved market performance."[14]

[13] Williams College. "Climate Action Plan 2022" https://docs.google.com/document/d/1rbF3knDxPEw-2yPk4AetG3urH1HSvTh8HBPmXtgTJYQ/edit#heading=h.ympd y6we0762

[14] Boffo, R., Patalano, R. OECD. "ESG Investing: Practices, Progress and Challenges", 2020. www.oecd.org/finance/ESG-Investing-Practices-Progress-and-Challenges.pdf

The Morgan Stanley Study[15] of over 10,000 funds found:

1. There is no financial tradeoff in the returns of sustainable funds and traditional funds. No consistent or statistically significant difference in total returns existed between ESG-focused and traditional mutual funds.

2. Sustainable funds may offer lower market risk. Sustainable funds experienced a 20% smaller downside deviation than traditional funds, a consistent and statistically significant finding.

The Morgan Stanley Study, along with others, indicate that a comparative analysis between ESG Funds and other mutual funds bolsters favorable perceptions of sustainable investing, which are becoming more widely accepted among investors and asset managers, who see potential for sustainable portfolios to yield attractive financial returns, alongside positive environmental or social impact. The Morgan Stanley Study found that: U.S. sustainable equity funds outperformed their traditional peer funds by a median total return of 4.3 percentage points. U.S. sustainable equity funds' median downside deviation was 3.1 percentage points less than traditional peer funds.

As for market cycles or long-term volatility, the same Morgan Stanley Study referenced above found that "in years of turbulent markets, such as 2008, 2009, 2015 and 2018, sustainable funds' downside deviation (a measure of downside risk that focuses on returns that fall below a minimum threshold or minimum acceptable return) was significantly smaller than traditional funds." Based on this information, adding ESG funds to a retirement plan lineup appears to be financially prudent.

The analysis of ESG fund performance unlike any other supports the broader narrative that incorporating environmental, social, and governance considerations into investment strategies can contribute to financial resilience.[16]

Appropriately, when funds are being considered in a retirement plan, ESG funds should at least be part of the conversation and analysis, as ESG funds seek to improve financial outcomes with an appropriate risk/return analysis.

Local scope: Williams College

To assess the relevance of these national performance and variance results of sustainable investment options, we conducted a comprehensive analysis of the retirement investments data from Williams College.

Data Overview

The primary data source for the performance evaluation was the TIAA website,[17] which provided a comprehensive list of available investment options not only for Williams College but also for a majority of other U.S. colleges. While the website offered essential information such as fund types, annual return rates, and, in some instances (~20% of the investment options), risk metrics, monthly and yearly performance data of funds/bonds were notably absent. Attempts to obtain this performance data through direct contact with the TIAA office and online searches proved unsuccessful.

To overcome this challenge, a detailed analysis of the HyperText Markup Language (HTML) data of each fund's individual pages on the TIAA website was conducted. While the TIAA presented performance graphs for individual funds over the years, the crucial underlying data for comparative analysis was not readily available. Recognizing that the individual performance graphs must be based on a hidden table of data undisclosed by TIAA, an examination of HTML codes led to the discovery of the code responsible for the data in the graphs. A solution emerged using the "pandas" library in Python, specifically tailored for web scraping. (For code access, please send your request to diliara.sadykova.04@gmail.com.)

Furthermore, we conducted an extensive analysis of the available investment options offered by TIAA across over 40 colleges in the United States. This analysis encompassed institutions with diverse profiles, including liberal arts colleges and larger university entities. The examination involved a thorough review of their websites and retirement plans,

15 Morgan Stanley. "Sustainable Investing Offers Financial Performance, Lowered Risk." 2019. https://www.morganstanley.com/content/dam/msdotcom/ideas/sustainable-investing-offers-financial-performance-lowered-risk/Sustainable_Reality_Analyzing_Risk_and_Returns_of_Sustainable_Funds.pdf

16 Hale, J. The ESG Advisor. "Takeaways from a Record Year for Sustainable Funds in the U.S." 2021. https://medium.com/the-esg-advisor/takeaways-from-a-record-year-for-sustainable-funds-in-the-u-s-f66d02ba74c7

17 TIAA. "View All Investments - Williams College." https://www.tiaa.org/public/tcm/williams/view-all-investments

unveiling 10 additional ESG funds and bonds that are actively invested in these institutions but not yet implemented at Williams College.

These newly identified ESG funds and bonds, along with their corresponding performance and variance metrics, have been integrated into our considerations. They emerge as prime candidates to be proposed to the Williams' HR office for implementation due to their proven track record as sustainable options actively utilized by colleges similar to Williams. In the subsequent sections, these funds will take center stage in our analysis, providing a focal point for comparison with other conventional funds.

Performance and Variance Metric Analyses

The methodology employed for analyzing the TIAA investment options dataset started with importing and cleaning the data in R. (For R code access, please send your request to diliara.sadykova.04@gmail.com.) Upon inspecting the dimensions of the cleaned dataset using the "dim" function, it was revealed to consist of 38 rows and 108 columns. 28 rows encompass Williams College's available funds, comprising both conventional and sustainable options, while an additional 10 rows feature newly discovered green funds from other colleges. The columns correspond to the time period, spanning 8 years from 2015 to 2023. This specific timeframe was selected for its representativeness, encapsulating multiple economic business cycles and aligning with the inception dates of the funds under consideration.

Ranking Performance of Williams' existing funds and bonds by their performance and variance over the years

Subsequently, exploratory data analysis was conducted, generating graphs to rank the performance of Williams' existing funds and bonds based on their monthly returns. Plots were created for "AnnualPercent," "SD" (standard deviation), and "CoefOfVariation" (Coefficient of Variation) using the "ggplot2" library. Rows which are highlighted are Williams College available ESG funds: CREF Social Choice Account (QCSCPX) and TIAA-CREF Social Choice Low Carbon Equity Fund Institutional (TNWCX).

Funds/Bonds ranked by Annual Percent – the annual growth of an asset.

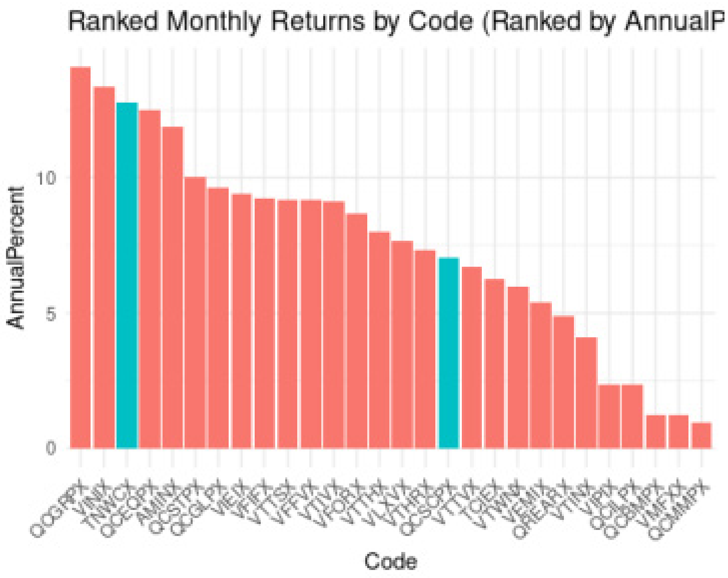

Fig.2. Funds/Bonds ranked by Annual Percent – the annual growth of an asset.

Analysis: TNWCX is ranked top-3 and QCSCPX top-17 out Williams' 28 available investment options. These results suggest the presence of existing ESG funds that outperform conventional ones within the investment portfolios. This underscores the potential of sustainable investment choices in generating growth compared to their conventional counterparts.

Funds/Bonds ranked by the standard deviation of the asset's value. Standard deviation (SD) is a statistical measure that quantifies the amount of variation or dispersion in a set of values.

In the context of an asset's value, calculating the standard deviation helps investors understand the degree of volatility or risk associated with the asset's performance.

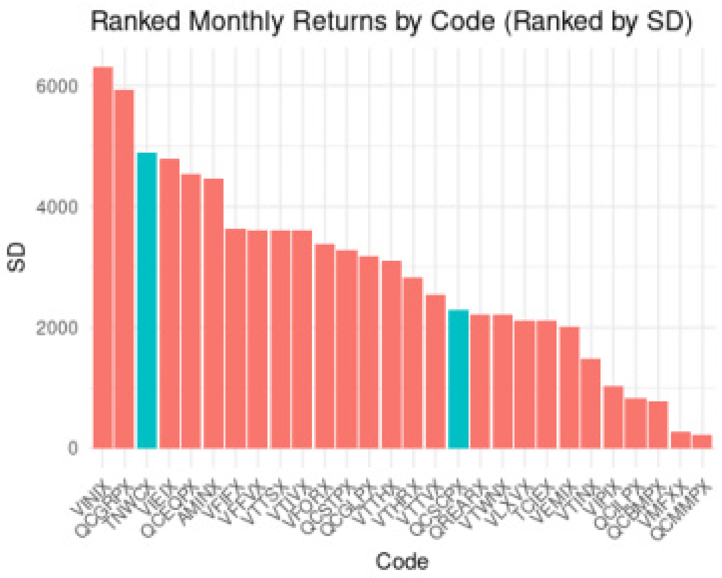

Fig.3. Funds/Bonds ranked by SD.

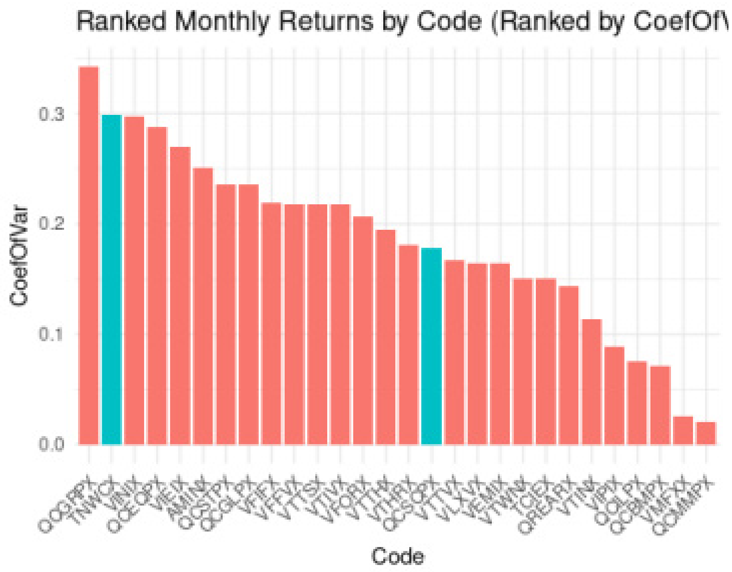

Fig.4. Funds/Bonds ranked by Coefficient of Variation.

Analysis: TNWCX is positioned in the top-3, and QCSCPX is ranked top-17 among Williams College's 28 available investment options based on their Standard Deviation (SD). Notably, these rank numbers align closely with their respective Annual Percent Growth rankings. This correlation implies that TNWCX, while delivering high returns, is also characterized by strong volatility. In contrast, QCSCPX, despite not yielding as significant returns, demonstrates a comparatively more stable performance. The consistent rank alignment between SD and Annual Percent Growth underscores a crucial trade-off in investment decisions between returns and volatility.

Funds/Bonds ranked by Coefficient of Variation - statistical measure that expresses the relative variability of the fund's returns, considering its standard deviation in relation to its mean: sd/mean

Analysis: TNWCX holds the top-2 position, while QCSCPX secures the top-16 rank among Williams College's 28 available investment options, as determined by their Coefficient of Variation (CV). The CV, which considers both variance and performance, provides a comprehensive view of risk-adjusted returns. In this context, these rankings emphasize that certain ESG funds, when adjusted for variance, outperform conventional options (lower CV is better than higher CV).

Furthermore, comparative analyses were performed to assess the performance of Williams's existing funds and bonds in comparison to green funds/bonds from other colleges. Different colors were assigned to highlight specific codes in the plots, distinguishing between Williams' green funds/bonds (turquoise) and those from other colleges (coral). The use of the "dplyr" library facilitated data manipulation and the creation of new columns based on specific criteria, while the `case_when` function was employed for conditional coloring of data points in the plots.

The motivation for conducting this comparative analysis is to go beyond evaluating Williams College's funds and bonds in isolation. It aims to gauge their performance relative to green funds/bonds offered by other colleges. The primary objective is to identify environmentally conscious funds with strong risk-adjusted returns, intending to propose their implementation within Williams College's retirement investments portfolio.

Ranking Williams' existing funds/bonds + additional green funds/bonds from other colleges by their Annual Percent:

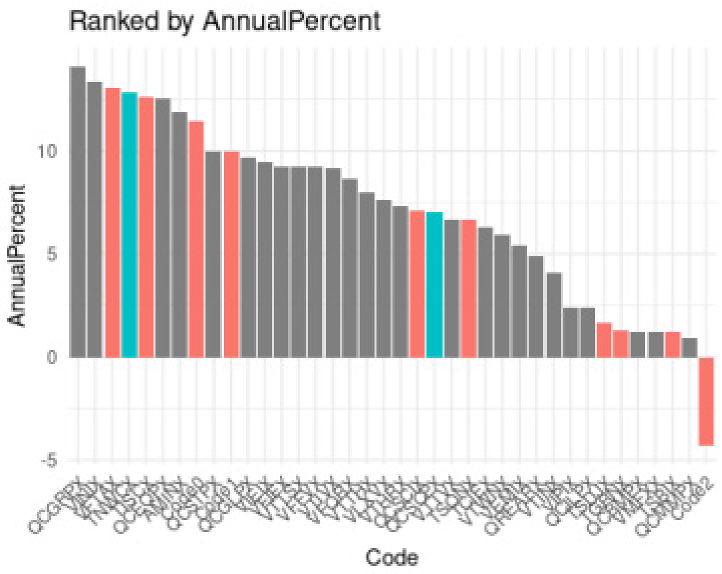

Fig.5. Williams' existing funds/bonds with additional green funds/bonds from other colleges ranked by Annual Percent.

Analysis: Other colleges feature four ESG funds with impressive relative annual performance: Vanguard FTSE Social Index Fund Admiral Class Shares (VFTAX), TIAA-CREF Social Choice Equity Fund (Institutional) (TISCX), TIAA Access Vanguard FTSE Social Index, and TIAA Access TIAA-CREF Social Choice Intl Eq. These funds emerge as compelling options, not only for their financial performance but also for the non-monetary benefits they bring. Consideration of these funds for potential inclusion at Williams would align with a holistic approach to sustainability investing.

Ranking Williams' existing funds and bonds + additional green funds/bonds from other colleges by their SD

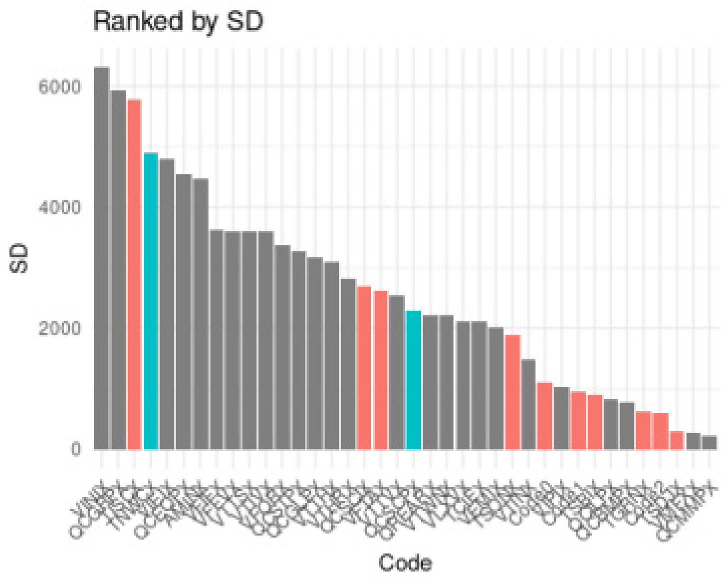

Fig.6. Williams' existing funds/bonds with additional green funds/bonds from other colleges ranked by SD

Analysis: Notably, among the high-performing ESG funds, only one—TIAA-CREF Social Choice Equity Fund (Institutional) (TISCX)—exhibits a high relative volatility. Vanguard FTSE Social Index Fund Admiral Class Shares (VFTAX) demonstrates a medium level of relative volatility, while the other two high-performing funds appear relatively stable. This observation instills confidence that ESG funds, on the whole, showcase both high performance and stability. Such a combination is reassuring and should alleviate concerns associated with implementing these assets or similar ones within Williams College's investment options.

Ranking Williams' existing funds and bonds + additional green funds/bonds from other colleges by their Coefficient of Variation

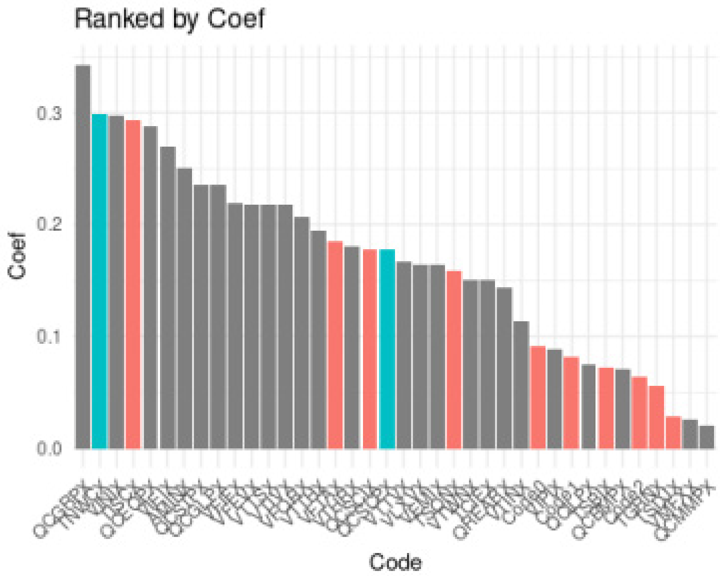

Fig.7. Williams' existing funds/bonds with additional green funds/bonds from other colleges ranked by Coefficient of Variation.

Analysis: The Coefficient of Variation (CV) mirrors the patterns observed in Standard Deviation (SD), indicating the presence of sustainable funds implemented in other colleges that showcase risk-adjusted returns outperforming conventional funds. This underscores the importance for Williams to explore these or similar funds. In addition to contributing to environmental justice, these funds offer not only non-monetary benefits but also demonstrate the potential for standard, high monetary returns.

In the time-series analysis, subsets of different types of investment options were created, focusing on green funds and bonds as well as conventional ones. The subsets were designed to include all available options and, separately, the best options (with best performance) within the green funds and bonds category (Williams + other Colleges options). The goal was to assess the mean performance of these subsets over time.

Subsequently, time-series linear graphs were generated using the "ggplot2" and "tidyr" libraries in R. The graphs depict the performance trends over time for all available options and the best options within each category. These visualizations aid in understanding the temporal patterns and relative performance of different investment options, allowing for informed decision-making.

Time-series

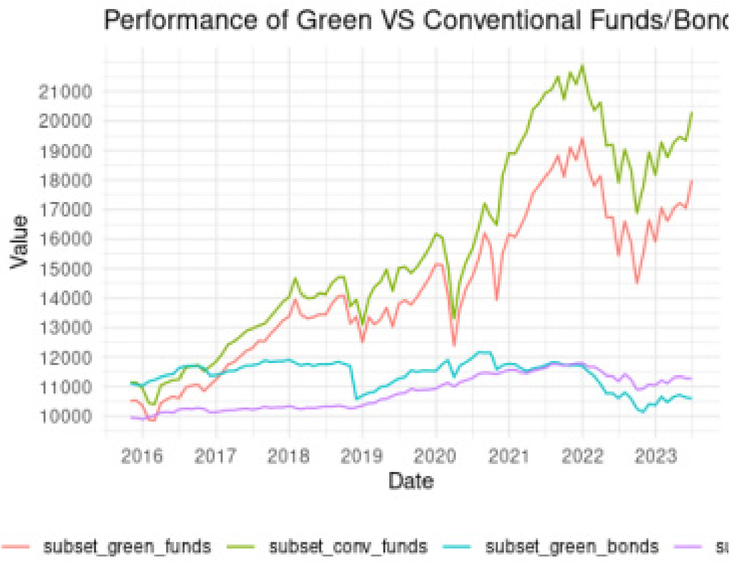

Fig.8. A linear graph (time-series) for all options of different types of investment options.

Analysis: Examining the growth of ESG and conventional funds/bonds, considering all available sustainable assets, reveals a trend. Conventional funds consistently outperform ESG funds, and while conventional bonds initially fare better than conventional funds, they eventually face challenges and fall behind. This time-series graph presents a potentially discouraging outlook for implementing new ESG assets, as it indicates a persistent advantage for conventional assets over the years. The data suggests that, over time, conventional assets tend to exhibit stronger performance compared to their sustainable counterparts.

Modified Analysis:

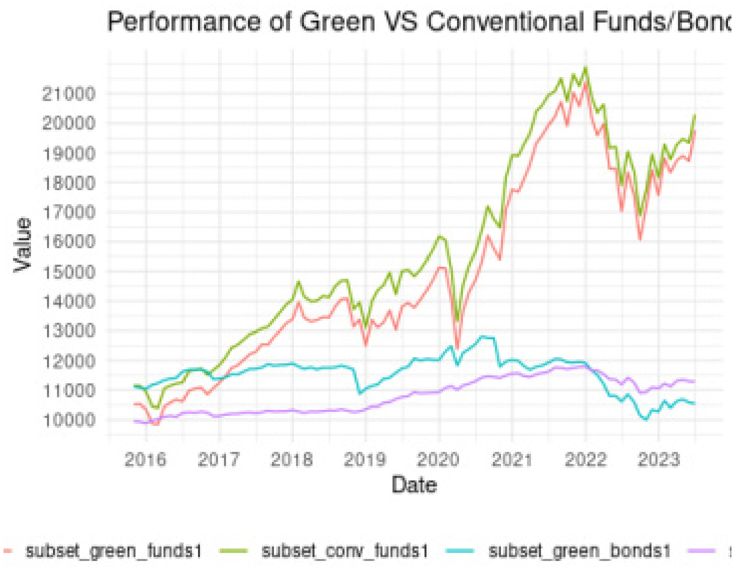

Fig.9. A linear graph (time-series) for modified options of different types of investment options.

Analysis: Upon excluding outliers from additional sustainable funds and bonds sourced from other colleges (not represented at Williams) with poor performance (note that the focus of this paper does not delve into the reasons for their inclusion in other colleges' investment options), a reevaluation of the time series within this refined subset reveals new trends. The situation with ESG bonds demands further investigation, as the limited availability of sustainable bonds introduces potential statistical errors.

However, a noteworthy development emerges as ESG funds begin to close the gap with conventional funds, trailing only slightly behind. The convergence of their mean values and growth rates with those of conventional funds positions them competitively, especially when factoring in the non-monetary benefits discussed in preceding sections, including climate justice considerations. These findings at the college level align with the performance analysis of ESG assets conducted by Morgan Stanley.

Conclusion: the implementation of more sustainable retirement investment options emerges as pivotal. From both monetary and non-monetary perspectives, ESG funds prove attractive for Williams College. This strategic shift aligns with broader trends in sustainable investing and climate action, reinforcing the rationale for adopting ESG-focused assets in the College's retirement investment portfolio.

Further Steps

1. Engagement with Williams College Offices

Throughout the project, various management and academic offices at Williams, including the Statistics and Economics departments, the President's Office, the Provosts, the HR Office, and the Investment Office, were actively contacted to propel the project forward. To sustain momentum, ongoing collaboration with the Investment Office and their retirement committee is imperative, ultimately facilitating the implementation of more sustainable retirement investment options through the HR office.

2. Communication of ESG Fund Additions to the Williams Community

The integration of ESG funds demands a robust communication strategy directed at the Williams community. This educational effort should be woven into broader financial literacy initiatives, emphasizing the significance of saving and long-term investing while highlighting the interconnectedness with climate action and justice. Exploring the creation of an educational website page, akin to SUNY's model,[18] stands as a viable option.

3. Institutional Survey/Focus Groups Among Staff/Employees

Gauging the interest of employees in incorporating ESG funds into the investment platform is pivotal. Conducting institutional surveys or focus groups helps determine whether the addition or replacement of current funds with ESG options aligns with employee preferences. This insight informs subsequent actions, such as adding one or several ESG funds or establishing a default option.

4. Proposal to Sign the Sustainable Retirement Plans Pledge

A proposal to sign the Sustainable Retirement Plans Pledge,[19] developed by the International Endowments Network, is recommended. This pledge underscores the belief that university employees deserve a spectrum of sustainable investing retirement fund options, considering

[18] State University of New York (SUNY). "Sustainable Funds." https://www.suny.edu/retirement/sustainable-funds/

[19] https://www.intentionalendowments.org/sustainable_retirement_pledge

environmental, social, and governance factors. The pledge, already endorsed by 12 U.S. colleges, including fellow liberal arts colleges, aligns with the goals of risk reduction, sustainable development, and enhanced financial returns.

5. Expansion of Research and Collaboration with Other Colleges

After the implementation of more options of sustainable funds/options at Williams, efforts should be expanded to connect with other colleges. By leading the charge in transforming the field of retirement investments, Williams can foster collaborations with institutions like Amherst College (already contacted) and others, advancing sustainability in the education sector.

6. Beyond TIAA Limitations

Addressing concerns raised about TIAA in the UPenn research and recognizing the limited options of ESG assets offered by TIAA, conversations with the HR and the Investment Office should explore openness to alternative platforms. Diversifying options beyond TIAA ensures a comprehensive approach to sustainable retirement investments.

7. Calculation of GHG Emissions from Retirement Investments (Scope 3)

While complex, calculating GHG emissions from retirement investments (Scope 3) at Williams can serve as a compelling avenue to provide additional evidence for the implementation of ESG funds/bonds. This, however, is recommended as one of the final persuasion strategies due to its complicated nature.

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Analyzing the Factors Affecting the Incidence of Foreign Direct Investment (FDI)

Dylan Safai, Nelson Del Tufo, Dylan Mealey

I. Introduction

Headlines such as "Korean phone manufacturer opens new factory in Germany," "London fashion brand expansion into Brazil," "Mexican automotive industry shocked by decision of United States to Close Mercaderos" (Dojan S-A, 2023) seem unrelated at first glance. However, they share one common theme: foreign direct investment.

Beginning with the colonial development of European powers, foreign direct investment (FDI) has played a pivotal role in the global economy for centuries. The current era of FDI began in the aftermath of the Second World War with post-conflict reconstruction initiatives, such as the Marshall Plan, gaining prominence. This momentum was subsequently propelled by events like the fall of the Berlin Wall and the growth of globalization (United Nations, 2017). The decade following the demise of the Soviet Union marked a transformative period characterized by reduced trade barriers, increased economic cooperation, and a movement towards a greater free exchange of ideas (Boughton, 2002).

Liberalization and globalization facilitated an upswing in foreign direct investment, a term the International Monetary Fund defined as, "cross-border investment in which an investor resident in one economy establishes a lasting interest in and a significant degree of influence over an enterprise resident in another economy" (IMF Glossary). Today, the top recipients of FDI are the United States, China, and Brazil, accounting for $109 billion, $21 billion, and $20 billion respectively. The top outflows of FDI include the United States with $110 billion and Germany with $57 billion (OECD, 2022).

As FDI continues to experience a boom with the reopening of superpowers like China after the lifting of Covid restrictions, work needs to be done to better understand the factors affecting the incidence of FDI. This empirical research paper attempts to do just that, as we look for indicators of foreign direct investment.

II. Literature Survey

Frameworks

Foreign direct investment takes on various forms, broadly categorized as horizontal, vertical, platform, and conglomerate. Horizontal FDI involves establishing a branch in a new country, replicating existing operations. Conversely, vertical FDI occurs when a company acquires an auxiliary entity in a new country to strengthen a specific aspect of its original operations. Platform FDI entails setting up manufacturing facilities in a new country and exporting the produced goods to a third nation. Lastly, conglomerate FDI refers to investing in an entirely unrelated business in a foreign country (Hintošová, 2021). An example of this category is the American company Walmart making a bid for the Indian company Tata Motors.

Numerous studies have explored the frameworks commonly underlying the process of FDI; one prominent model that has emerged is Dunning's Ownership, Location, Internalization(OLI) model, also known as the eclectic paradigm. This three-step framework is often employed by companies to assess the potential benefits of investments in specific countries (Sharmiladevi, 2017).

Ownership, the first branch of the model, pertains to a company's ability to maintain a competitive edge within the country it ventures into. This encompasses rights to brand protection, copyright laws, and patent rights, among others. The location aspect, perhaps the most pivotal factor, considers geographic proximity to a labor force, tax incentives, natural resource availability, and shipping potential. Additionally, the gravity model of FDI, described in a study by Bikash Mishra of Ravenshaw University, correlates FDI flows with the size of the host and source countries and the distance between them (Mishra, 2019).

The third dimension of Dunning's model, internalization, focuses on an organization's capacity to internally produce goods rather than outsourcing to third parties. This internalization advantage often leads businesses to engage in staff augmentation to ensure an optimal workforce (Sharmiladevi, 2017).

FDI also aligns with different frameworks based on the objective it serves within a country. Market-seeking FDI involves firms investing in foreign markets to expand their consumer base and establish a foothold in new markets. Conversely, resource-seeking FDI centers on companies investing specifically for resource extraction purposes (Caon, 2020). For instance, a British company investing in a diamond mine in the Democratic Republic of the Congo exemplifies this type of FDI, aiming to extract resources for commercial gain.

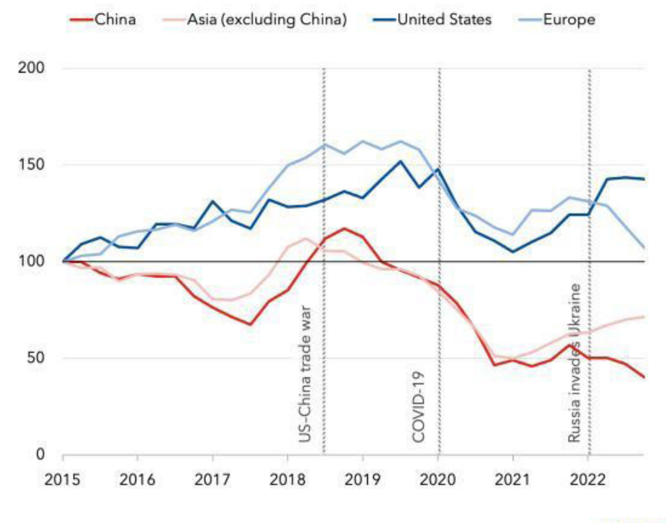
Impacts of FDI

FDI serves as a catalyst for economic growth in host countries, yielding substantial benefits. Notably, FDI inflows are directly linked to capital accumulation, demonstrating a significant 2.31% average increase in capital for every percentage rise in FDI (Ezo Emako et al. 2023). This influx not only introduces technical knowledge of industry but also spurs economic output by introducing innovative capital goods. Moreover, multinational corporations, often associated with FDI, tend to create employment opportunities with superior working conditions and higher wages, prompting local firms to enhance their efficiency, thus bolstering the economy (IMF; Razin et al., 2001).

However, while FDI positively impacts human capital, contributing to a remarkable 2.38% increase (Ezo Emako et al. 2023), its social implications exhibit a complex interplay. Sectors like mining and agriculture, reliant on low-skilled labor (including child labor), show a decrease in school enrollment due to FDI (OECD 2007). Conversely, FDI in manufacturing typically enhances educational access. Despite the overall improvement in living standards facilitated by FDI, challenges surface in its wake. Corporations might exploit unfair competition, leveraging low wages and labor standards (OECD 2007). Additionally, concerns arise regarding human and labor rights violations, particularly in countries where governance and enforcement mechanisms are inadequate.

FDI and Policy Effects

Amidst the global disruptions caused by the COVID-19 pandemic, researchers scrutinized the intricate relationship between Foreign Direct Investment (FDI) and policy making. Imad A. Moosa Ebrahim Merza conducted a study highlighted in the



Sources: fDi Markets; and IMF staff calculations.

Winter 2022 Future Business Journal, revealing how the pandemic's chaos reshaped fundamental dynamics of FDI politics. The breakdown of global supply chains forced a profound recalibration, compelling companies to pivot toward domestic sourcing, redefining proximity as a new focal point for supply. Concurrently, governments recognized the imperative of bolstering local production, particularly evident in the production of essential medical supplies, like vaccines (Moosa, 2022).

This pivot towards localized production acted as a catalyst for FDI, especially in the realm of vaccine development and delivery. The study discovered a discernible global shift, characterized by burgeoning anti-globalist and anti-FDI sentiments. This trend found validation in movements like America First in the United States and echoed in the rise of right-wing leadership across various nations.

The study's core lies in its belief that the pandemic, despite its detrimental impact on FDI flows, catalyzed a pivotal moment for reflection. Moreover, this transformative period foretells a trajectory away from peak globalization, a perspective echoed by Gray. His assessment paints the pandemic as more than a temporary disruption; instead, it heralds a turning point in history, fundamentally reshaping the global landscape (Moosa, 2022).

One example of the reshaping of the global landscape is the significant regulatory measures imposed by the Biden Administration on semiconductor chip exports to China in early October 2023. These measures included a ban by the U.S. Department of Commerce, encompassing H100, A800, and H800 series advanced artificia intelligence chips destined for China (Freifeld, 2023). While proving detrimental to China in terms of Foreign Direct Investment, this move has sparked contrasting perceptions within the country itself.

Amidst these stringent regulations, some within China perceive this as an opportunity for domestic growth and technological self-sufficiency. More than 1,500 companies are already entrenched in the semiconductor industry, and they anticipate leveraging their existing foothold by spearheading their domestic production of integrated circuits and AI chip training. Interestingly, this turn of events has drawn FDI comparisons among some in China to the historic Great Leap Forward era under Mao Zedong (LoC, 2015). During that period, millions of Chinese peasants united in an ambitious drive to boost domestic production, famously employing homemade backyard furnaces to manufacture steel (LoC, 2015). Mao had envisioned catapulting China to the forefront of global steel production, spurring nationwide efforts to achieve this goal. Ultimately, the Great Leap Forward caused social and economic devastation, with crippling outcomes for the Chinese society.

III. Methodology

Data Collection

Building upon our comprehensive literature review, this paper aims to better understand the intricate factors steering the incidence of FDI. In order to achieve this, data was collected from a number of databases on the factors we viewed as viable. This was not always a simple process due to the complexity of FDI and the limited amount of data available in public databases.

Nevertheless, during the collection process, we found data provided by existing literature on the incidence of FDI in a given economy longitudinally. Due to both the rapidly changing nature of the modern economy, and to the increasing sparseness of data moving backwards in time, we chose to focus our study only on the incidence of FDI inflows over the course of the past 25 years of available data, from 1998 to 2022. This longitudinal data on FDI was sourced from the World Bank, which provides comprehensive information on global economies and political environments in a number of publicly available data banks on their website. We chose to analyze the 190 economies which these databases could provide information. A full list of the countries analyzed can be found in the appendix.

We sourced our response variable of net FDI inflows in USD from the World Bank's dataset categorizing "world development indicators." Additionally from this source, we gathered data on GDP (in constant 2015 USD), GDP per capita (PPP measure), trade as a percentage of GDP, employment in industry as a percentage of total employment, and natural resource rents as a percentage of GDP. These variables reflect, respectively, the size of the market in the receiving country, the level of openness to trade, the level of industrialization in a given economy, and the availability of material inputs, which are all theorized to be positively correlated with FDI incidence (Lim, 2001). Additional data was sourced from the World Bank's "governance indicators" dataset, which contains data on government effectiveness and openness. We took data on the World Bank's measures of Control of Corruption, Government Effectiveness, Rule of Law, Political Stability and Absence of Violence/Terrorism, Voice and Accountability, which are each measured on a scale of -2.5 to 2.5. These measures were chosen as indicators of the investment climate, since "an unstable political situation, or economic instability would make the host country less attractive for all types of FDI" (Lim, 2001).

Finally, we wanted to take into account historical factors which may affect the incidence of FDI in a given economy. Specifically, we wanted to take into account the potential effect of the fall of the eastern bloc on the incidence of FDI. In our model, we constructed an indicator variable termed "Communist" to delineate countries that had experienced a communist government for over a decade during the twentieth century. The prevailing literature indicates that the "shift from a communist regime doesn't inherently guarantee the establishment of a robust market economy" (Fabryand Zeghni, 2006). These transitioning nations undergo swift micro and macro reforms to foster internationally competitive environments, nurturing the growth of market economies and facilitating private sector development. Seeking integration into the global economy, many such nations opt to join organizations like the European Union or ASEAN, expediting their transition.

Moreover, the aforementioned studies emphasize the pivotal role of increased inward FDI for these transitioning countries to maintain pace with global economic developments. They underscore how FDI contributes to modernization across various spheres by introducing Western technologies (Fabry and Zeghni, 2006). Our objective lies in comprehending whether a nation's historical experience with communism has an effect on FDI inflows today.

Model and Variables

Due to assumptions of non-linear relations between variables and for the sake of interpretability, some of the variables analyzed underwent transformations over the course of the modeling process. Rather than using raw FDI inflows as a response variable, we took the log of this variable, in order to be able to interpret coefficients in terms of percent changes rather than unit changes, which in this case would have come in the form of U.S. dollars. We also took the log of GDP, as well as GDP per capita, for similar reasons. Not only was this done due to the expected consistency of elasticity between these terms and FDI, but also for the sake of interpretability; this transformation allowed us to determine that a percent change in GDP will have the effect of producing a 0.95 percent change in FDI.

Additionally, rather than using the value of GDP for a given year in the model, we created a lag variable for GDP in order to address issues of reverse causality that occur when regressing FDI on GDP; essentially, FDI inflows are determined by the market size, but FDI inflows also change the size of the market. A lag of five years was chosen to overcome this issue, as evidenced by the fact that institutions developing investment plans were likely to use data from four or five years prior to the date of investment.

The creation of this lag variable resulted in a decline in the number of available observations by approximately 20% since five years is one fifth of the total time analyzed. This decline in observations, and the general lack of consistently reported data in all countries over the course of the past 25 years should be kept in mind when looking at the results of our regression analysis.

We chose to use a robust ordinary least squares regression model to model the relationship between our response variable (bet FDI inflows), and GDP, GDP per capita, Average Governance Indicator Score, Employment in Industry, Trade as a percentage of GDP, Natural Resources, and a nations' status as formerly communist. This model is shown below:

$$(\text{lFDI})i = \beta0 + \beta1(\text{logged value of GDP laglGDP}) + \beta2(\text{lPPPCapita}) + \beta3(\text{GovIndicator}) + \beta4(\text{IndustryEmployment}) + \beta5(\text{Trade}) + \beta6(\text{NaturalResources}) + \beta7(\text{Communist}) + \text{Ui}$$

This model represents our best attempt at accurately modeling the factors that influence foreign direct investment globally, using the data and methods available to us. Descriptions and summary statistics for the variables used in this model can be found below.

IV. Data Description

VARIABLE AND MODEL DESCRIPTIONS

Variable Name	Definition	Scale	Database
lFDI	The log net value of Foreign Direct Investment inflows into a given economy. **This is our response variable.**	Numeric (logged)	World Bank Governance Indicators
GovIndicator	Average Value of a country's score on five measures of state capacity and liberality: control of corruption; Government Effectiveness; Rule of Law; Political Stability and Absence of Violence/Terrorism; Voice and Accountability.	-2.5 to 2.5	World Bank Governance Indicators
laglGDP	The log value of Gross Domestic Product, measured in constant 2015 USD, lagged by five years to address issues of reverse causality	Numeric (logged)	World Bank Development Indicators
lPPPCapita	The log value of Gross Domestic Product per capita measured using a purchasing power parity conversion rat2 tied to 2017 USD	Numeric (logged)	World Bank Development Indicators
IndustryEmployment	The percentage of the total working population employed in industrial processes.	Numeric	World Bank Development Indicators
Trade	The value of international trade in a country as a percent of GDP.	Numeric	World Bank Development Indicators
NaturalResources	The value of natural resource rents in an economy as a percentage of GDP, calculated by estimating the price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs	Numeric	World Bank Development Indicators
Communist	A dummy variable indicating whether a country has had a communist government for more than a decade during the twentieth century	0 for non communist, 1 for formerly communist	World Population Review

SUMMARY STATISTICS

Log FDI Summary Statistics:

```
. sum lFDI
```

Variable	Obs	Mean	Std. dev.	Min	Max
lFDI	4,349	20.39004	2.622714	10.36072	27.32154

Government Indicator Summary Statistics:

```
. sum GovIndicator
```

Variable	Obs	Mean	Std. dev.	Min	Max
GovIndicator	4,665	-.071186	.883251	-2.381896	1.980171

Lagged Log GDP Summary Statistics:

```
. sum laglGDP
```

Variable	Obs	Mean	Std. dev.	Min	Max
laglGDP	3,654	24.09874	2.257053	18.63164	30.57148

Log GDP (PPP) Summary Statistics:

```
. sum lPPPCapita
```

Variable	Obs	Mean	Std. dev.	Min	Max
lPPPCapita	4,511	9.225272	1.193515	6.370018	11.96783

Industry Employment Summary Statistics:

```
. sum IndustryEmployment
```

Variable	Obs	Mean	Std. dev.	Min	Max
IndustryEm~t	4,270	19.46766	8.298363	2.195539	59.5787

Trade Summary Statistics:

```
. sum Trade
```

Variable	Obs	Mean	Std. dev.	Min	Max
Trade	4,154	87.77725	54.01988	2.698834	442.62

Natural Resources Summary Statistics:

```
. sum NaturalResources
```

Variable	Obs	Mean	Std. dev.	Min	Max
NaturalRes~s	4,440	7.099953	11.12232	0	88.59235

Formerly Communist Summary Statistics:

```
. tab Communist
```

Communist	Freq.	Percent	Cum.
0	3,600	75.79	75.79
1	1,150	24.21	100.00
Total	4,750	100.00	

V. Results

FIGURE 1

VARIABLES	(1) Foreign Direct Investment
laglGDP	0.95***
	(0.01)
lPPPCapita	0.09**
	(0.04)
GovIndicator	0.18***
	(0.04)
IndustryEmployment	-0.02***
	(0.00)
NaturalResources	0.00
	(0.00)
Trade	0.01***
	(0.00)
Communist	0.62***
	(0.05)
Constant	-3.62***
	(0.33)
Observations	2,837
R-squared	0.78

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A few things should be kept in mind with regard to the interpretation of the results of our regression model. First of all, foreign direct investment is an extremely broad topic, as evidenced by our literature review, and the result of this model gives us little information about the details of any specific investments in any given country. Essentially, our model tells us nothing about what factors might influence a corporation's decision to build a piece of physical infrastructure specifically, or to purchase an existing factory, or undertake any other specific type of FDI. It only tells us what factors affect FDI broadly.

Additionally, although we believe our model to be robust and broadly indicative of FDI incidence, there were several additional factors that we would have liked to consider, and which could warrant further investigation. This will be explored in more detail in the conclusion section of this paper.

As for the results of our OLS regression analysis, Figure 2 shows the full interpretable results of each variable, holding all else constant. Probably the most surprising finding is the high p-value for natural resource rents within the model. The coefficient of .00337 and robust standard error of .00332 suggest that natural resource rents are not statistically significant when holding all other factors constant, and that we cannot reject the null hypothesis that natural resource rents have no effect whatsoever on the incidence of FDI. This is an interesting finding due to the ample literature that connects FDI to cheap material inputs in the receiving country. This result suggests that extractive economies are not those that are most attractive to foreign investment.

With the exception of natural resource rents, all other variables were found to be statistically significant, with a p value of less than .05, and low standard errors. One such statistically significant result was the coefficient of communism dummy variable. This coefficient of .62 suggests that having a communist history, holding all else constant, is associated with a nearly 86% increase in FDI when compared to a non-communist nation. This could be the result of the massive comparative influxes of FDI into formerly communist countries in the aftermath of the fall of the Iron curtain.

Another interesting result is that of industrial employment, which is slightly negatively associated with FDI. While this runs counter to existing literature which ties FDI to national level of industrialization, it is not all that surprising, when you consider that many highly industrialized countries have extremely low industrial employment. The United States, for instance, has the most advanced economy, and attracts large amounts of FDI, but has less than 10% industrial employment. Further work should be conducted to determine if high industrial employment is positively associated with FDI under any circumstances, or has a non-linear relationship with it.

FIGURE 2

Numeric (logged)	FDIbill	
-2.5 to 2.5	Gov Indicator	A 1 point increase in the Government Indicator yields a 0.200% increase in FDI
Numeric (logged)	laglGDP	A 1% increase in GDP yields a 1.593% increase in FDI
Numeric (logged)	lPPPCapita	A 1% increase in GDP Per Capita (PPP) yields a 0.097% increase in FDI
Numeric	IndustryEmployment	A 1 percentage point increase in Industry Employment (as a % of GDP) yields a 2.222% decrease in FDI
Numeric	Trade	A 1 percentage point increase in Trade yields a 0.895% increase in FDI
Numeric	NaturalResources	A 1 percentage point increase in Natural
		Resources yields a .332% increase in FDI
0 for non communist, 1 for formerly communist	Communist	A change from 0 → 1 in the Formerly Communist Indicator yields a 85.967% increase in FDI

FIGURE 3

VARIABLES	(1) Foreign Direct Investment
laglGDP	0.93***
	(0.01)
Constant	-1.76***
	(0.24)
Observations	3,393
R-squared	0.72

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Despite the results above, what is perhaps our key finding is an unsurprising one; the single factor with the most explanatory power to explain Foreign direct investment inflow is market size, in the form of GDP. A simple regression of FDI on GDP, shown in Figure 3 above, shows that differences in GDP between countries can explain more than 70% of the variation in FDI inflows between countries on its own. This value only rises to 78% when all other variables are included in the analysis. This does not mean that other variables are important in explaining net foreign direct investment inflows, but only that GDP is the most important factor by far.

Additionally, the coefficient for GDP hardly changes with the presence of other variables. With the simple regression model of FDI on GDP shown above, a 1% increase in GDP is associated with a 1.539% increase in FDI; in the full multiple regression model we used, it is associated with a 1.593% increase in net FDI inflows. This is further evidence that market size remains a paramount factor in determining the incidence of foreign direct investment, regardless of other factors.

VI. Conclusion & Further Research

Foreign direct investment (FDI), an influential force, has traversed the globe for centuries, originating from the dawn of nation-states, progressing through the era of the Silk Road, and persisting till present times amidst unprecedented levels of globalization. Following the conclusion of the Covid-19 pandemic, nations have been swiftly unveiling their borders at rates previously unimaginable.

Through this process, we took data from the World Bank Governance Indicators, World Bank Development Indicators, and World Population Review to determine what factors are the most influential and significant for determining the incidence of foreign direct investment in a given economy. Our results suggest that market size is the single most important factor for determining FDI inflows, but that other factors, such as GDP per capita, trade as a percentage of GDP, and a nation's communist history, also play an important role.

Our results raise questions for further research. As previously stated, foreign direct investment is a term which encompasses a broad range of economic activities, and our results give little indication of what sort of FDI is associated with what sort of factors. Thus, further research might involve creating different models for different types of FDI, though this would require finding and using different data sources.

Another question for further analysis would have to do with different sources of FDI. Different nations and different corporations may be influenced by different factors when it comes to making decisions about investing abroad, and it would be eye-opening to analyze these different sources of FDI separately, to determine if this is the case.

Finally, a third question to examine would be the impact of FDI within different income brackets. Investment in a developing economy may be associated with different factors (such as the aforementioned natural resource rents) when compared to investment in a developed economy. This question would be related in many ways to the first question about types of FDI, as investments in capital rich countries such as the U.S. are likely of a markedly different type than investment in labor rich developing economies such as Guatemala.

With our background in the literature and analysis of the results, we have arrived at a conclusion that tackles the initial concept we aimed to address. However, the closure of one door has unexpectedly revealed numerous new avenues, signaling the potential for a more intricate study in our group's future endeavors. This expanding lens presents an opportunity for policymakers, and businesses to navigate the complex landscape of FDI—its varied types, behaviors, and studies—to optimize its potential benefits. Our aspiration is for this project to transcend academic enrichment, resonating through its practical implications in helping to foster sustainable economic growth and promoting greater equity in global development.

VII. Appendix

List of Countries Analyzed

Afghanistan
Albania
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
The Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei
Bulgaria
Burkina Faso
Burundi
Cabo Verde
Cambodia
Cameroon
Canada
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo, Democratic Republic of the
Congo, Republic of the
Costa Rica
Côte d'Ivoire
Croatia
Cyprus
Czech Republic

Denmark
Djibouti
Dominica
Dominican Republic
East Timor (Timor-Leste)
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Eswatini
Ethiopia
Fiji
Finland
France
Gabon
The Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kiribati
Korea, North
Korea, South
Kosovo
Kuwait
Kyrgyzstan
Laos
Latvia
Lebanon
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Mauritania
Mauritius
Mexico
Moldova
Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
North Macedonia
Norway
Oman
Pakistan
Palau
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar

Romania
Russia
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent
Samoa
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
Spain
Sri Lanka
Sudan
Sudan, South
Suriname
Sweden
Switzerland
Syria
Taiwan
Tajikistan
Tanzania
Thailand
Togo
Tonga
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Vanuatu
Venezuela
Vietnam
West Bank and Gaza
Yemen
Zambia
Zimbabwe

VIF test for Regression Model

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. vif
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Variable	VIF	1/VIF
lPPPCapita	4.84	0.206630
GovIndicator	3.08	0.325130
laglGDP	1.85	0.539923
IndustryEm~t	1.81	0.552202
Trade	1.43	0.697390
NaturalRes~s	1.27	0.788344
Communist	1.17	0.852788
Mean VIF	2.21	

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National Hypocrisy: Implications of Wartime Values at Home During the Asia-Pacific War

Elizabeth Cheng

The First 30 Hours, the Time-Life-Fortune News Bureau reported global reactions to Japan's attack on Pearl Harbor.[1] In Los Angeles, general consensus deemed the "action itself [to seem] incredible" as citizens took "for granted" the burdens of total war that would ensue.[2] Itabashi Kōshū's statements in Haruko Taya Cook and Theodore F. Cook's Japan at War: An Oral History depict Japan as a "whole nation bubbled over, excited and inspired" after the attack.[3] However, as policy and media transformed the Asia-Pacific War into an ideological conflict, marginalized citizens of both countries struggled with heightening racial tensions and class inequality. Japan's lower classes and ethnic minorities struggled with broadening socioeconomic gaps as they were forced to sacrifice for the war. Amid rampant racism and discrimination policy in the United States, Japanese-Americans fought to prove their loyalty and humanity to white citizens and Black Americans endeavored to demonstrate their value in the military. Purported national ideals of freedom and equality, seen through wartime propaganda and intended to motivate civilian participation, exposed and exacerbated institutionalized class and racial inequality at home while providing opportunities for social advancement.

In Japan, propaganda emphasized equality and wartime heroism while distorting information to promote civilian sacrifice and mobilization. In Leaves from an Autumn of Emergencies, Tamura Tsunejirō discusses how the government failed to reveal "the truth about the war" to "win the support of the general population."[4] As many citizens, especially those in the lower classes, struggled with the strict rationing of necessities like coal and food distributions, a worthwhile ideological basis of war became necessary to motivate sacrifice.[5] Policymakers manipulated the presentation of information and "[spoke] of the equality of the country's ten million people" to present a simple narrative about the conflict's purpose catered toward civilians: upholding national values like equality.[6] Thus, civilians learned to live not in the war, but for it. This learning extended to children's schools, in which students "wrote to the soldiers of [their] gratitude for their fighting."[7] Glorifying soldiers' endurance magnified their heroism, crafting a role model of sacrifice and wartime mobilization for students. Formal teaching and propaganda strove to motivate citizens to sacrifice for the war on the basis of protecting values like the aforementioned "equality."[8]

However, as the war broadened existing socio-economic divides, Japan's crafted image of equality exposed exactly the opposite. While the lower classes fought everyday to avoid starvation, the rich monopolized resources in order to "circulate them back to the black market."9 Such manipulation of the economy to profit off the struggles of the poorest demonstrates the war's proliferation of social divides. The rich were not only already advantaged, but the limited resources of wartime enabled the wealthy to monopolize necessities — the "strong ate the weak"

1 Hulburd, David, "War Comes to the U.S. – Dec. 7, 1941: The First 30 Hours," *TIME-LIFE-FORTUNE News Bureau*, December 1941.

2 Hulburd, "War Comes to the U.S," Los Angeles, 1.

3 Cook, Haruko Taya and Cook, Theodore F., Japan At War: An Oral History, (New York: The New Press, 1992), 77.

4 Yamashita, Samuel, "Tamura Tsunejirō: Bittersweet, The Wartime and Postwar Diary of an Ordinary Kyoto Person," in *Leaves from an Autumn of Emergencies*, (Honolulu: University of Hawai'i Press, 2005), 109.

5 Yamashita, "Tamura Tsunejirō," 88.

6 Ibid, 97.

7 Cook and Cook, *Japan At War: An Oral History*, 343.

8 Yamashita, "Tamura Tsunejirō," 97.

9 Ibid, 85.

as they actively exploited and expanded the existing socio-economic gap.[10] Wartime propaganda like the aforementioned "equality" leads Tamura to later realize that the Japanese government's messaging regarding equality and heroism on the warfront is "pure semantics."[11] The contrast between supposed "equality" and the restrictive rationing of daily necessities that disproportionately impacted the poor exposed rampant class-based inequality.[12]

A similar contrast existed between American wartime values of freedom meant to motivate civilian mobilization and their true manifestations at home. In Our Mothers' War, Emily Yellin investigates President Theodore Roosevelt's speech about the United States' ideological basis for war, in which he identified "four freedoms," including "freedom of speech and expression" and freedom from "want" and "fear."[13] By attaching broad-base American ideals to the war, Roosevelt transformed the conflict into a cause with a relatable narrative. Black Americans especially saw themselves reflected in Roosevelt's wartime ideals, since the "freedoms" paralleled the rights for which they were fighting.[14] This fight for justice both on the warfront and home front partially succeeded as a motivator for civilian mobilization. Black war worker Hortense Johnson described her mindset as working to not "let [racial injustices] break your spirit, so you quit this struggle and turn the country over to Hitler."[15] Johnson further valued the fight abroad because she was fighting for similar rights at home, and thus became motivated to mobilize for the war.

However, this mirroring of values revealed national hypocrisy amid heightened racial tensions. The parallels between Roosevelt's speech and Black Americans' fight for freedom turned Roosevelt's stated values "hollow" — racial injustices at the time, including job discrimination and segregated armed forces, largely prevented the domestic application of wartime values.[16] The hypocrisy became embarrassingly apparent when German prisoners of war received front row seats at a performance meant for Black American troops.[17] Treating American troops as inferior to the enemy demonstrates the falsities of claimed freedoms. One New York Post columnist described the country as either "believers in the principles of democracy" or "a collection of the greatest frauds the world has seen."[18] As the United States became obligated to show the veracity of their ideological basis for war, the incongruence between American political values on the international stage and their domestic applications became apparent. Although these declarations of ideology were intended to motivate citizens to mobilize for the war, and justify reasons for entering the conflict, they also highlighted questions regarding their lack of authenticity in civilian life.

Such exposure of empty rhetoric provided opportunities for advocacy groups; without advancements in social justice, the ideals would remain fraudulent. The Black press leveraged this hypocrisy by spreading the "Double V campaign," in which Black citizens fought for both victory over facism on the war front and racial discrimination at home, as the two battles were aligned with one another.[19] Yellin's discussion of Jane Crow, or institutionalized discrimination faced by Black women, depicts how both civil rights groups and individual activists exposed empty values to further their advocacy.[20] As a labor union for Black workers and the NAACP planned a march in Washington D.C. to protest job discrimination, Roosevelt immediately worked to negotiate — the march would have been an obvious indicator of the lack of true justice in the United States, staining the American image of liberty and democracy.[21] Given existing racial tensions, such a demonstration would have also decreased public support at home and soldiers' morale on the war front. Roosevelt later issued an executive order to encourage participation in the national defense program "regardless

10 Yamashita, "Tamura Tsunejirō," 113.
11 Ibid, 97.
12 Ibid, 97.
13 Yellin, Emily, "Jane Crow: African-American Women," in *Our Mothers' War: American Women at Home and at the From During World War II*, (New York: Simon & Schuster, 2004), 208.
14 Ibid, 208.
15 Ibid, 208.
16 Bailey, Beth and Farber, David, "The "Double-V" Campaign in World War II Hawaii: African Americans, Racial Ideology, and Federal Power," in *Journal of Social History*, Vol. 26, No. 4 (Summer, 1993): 817-843.
17 Yellin, "Jane Crow," 220.
18 Ibid, 223.
19 Ibid, 212.
20 Ibid, 204.
21 Yellin, "Jane Crow," 204.

of race, creed, color, or national origin," demonstrating the success of leveraging the exposure of empty rhetoric.[22] Speaking up about obvious hypocrisy became more powerful than ever, as policymakers were forced to take action in order maintain the carefully crafted "moral standing of America in the concert of world nations."[23] Policy that mitigated job discrimination in defense industries provided Black women workers opportunities for social and political advancement. Many performed lack-luster jobs "with gusto" in hopes of proving to the nation that they were valuable citizens outside of domestic labor.[24] The opportunities of industry specific to wartime catalyzed such advancement.

In both Japan and the United States, empty rhetoric about equality and freedom led to realizations of the government's false messaging. A desire to fulfill the ideals of propaganda surrounding freedom led American policymakers to begin grappling with institutionalized inequality. Further discussion is needed to explore both countries' wartime exploitation of marginalized groups for manpower, the intersection of race and class-based discrimination, and how ideals manifested in unique ways for different marginalized groups. Despite the falsities of political values presented for the international stage, the declaration of ideals ultimately encouraged improvements in their domestic realities. Although these ideals have yet to be fully reflected in citizens' daily lives, it is clear that the war compelled leaders to create an idealistic, albeit perhaps unattainable, standard toward which to work.

22 Ibid, 204.
23 Ibid, 217.
24 Ibid, 214.

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Exploring Health Behaviors on Campus: A Study on the Resting and Eating Habits of Williams College Students

Ashley Kim

Abstract

This study aimed to investigate the relationships between health behaviors, including sleep habits and eating habits, among Williams College students. A sample of students completed a survey in which they were asked about themselves, their diet, and their activity. Consistent with past evidence, sleeping more is associated with having a healthier diet and a higher self-satisfaction with eating habits. Williams students who indicated in the study that they sleep earlier rated the healthiness of and satisfaction with their eating habits significantly more positively than students who reported sleeping later. Participants who rest more are more likely to feel like they eat healthier per week, and participants who feel like they eat healthier are more satisfied with their eating habits. Overall, among Williams students, better sleeping habits are associated with healthier eating habits and with more positive self-perceptions of one's diet. These findings provide valuable insights to the well-being of Williams College students and may potentially inform strategies for promoting physical and mental health on campus.

Keywords:
Diet, Sleeping, Relaxation, Health, Self-Satisfaction, Williams College

Introduction

While the individual significance of dietary and sleeping habits is widely acknowledged, the mutual influence between these essential human functions often receives insufficient emphasis in everyday discourse and practice, especially on college campuses. Practice of poor eating and resting habits are especially prevalent among college students, putting students at risk for health problems and jeopardizing academic achievement and performance, relationships, and happiness (Sheldon et al., 2007).

Past research corroborates the hypothesis that better resting habits among young people are associated with better diets. Among children, adolescents, and young adults, higher intake of unhealthy (e.g., processed, sugary) foods and drinks has been associated with worse sleep features (e.g., more hours of sleep, greater daytime sleepiness, greater sleep satisfaction), while consumption of healthy foods and drinks has been associated with better sleep quality (Godos et al., 2020). Unhealthy foods can affect hormone levels, which influence circadian rhythms; then, disturbed sleep-wake cycles can lead to a host of unwanted physiological and mental stressors as extreme as affective disorders and metabolic diseases (Li et al., 2018).

Important factors to consider regarding individuals' habits include not only the habit itself, but also the individual's thoughts and perceptions of their habit. Self-satisfaction with habits may be just as important to individuals as the actual healthiness of the habits. In fact, a study among Korean adolescents found that healthy eating is linked to higher sleep satisfaction, but not necessarily other indicators of better sleep (Hong & Peltzer, 2017).

Better resting habits include sleeping earlier and sleeping more; better diets include eating healthier foods (e.g., non-soft drinks, non-processed food). Past research highlights the significant link between good rest, a healthy diet, and optimal human functioning: we cannot optimize one without the others, especially in young people. This study will investigate the relationship between resting and dietary habits, as well as student satisfaction with these habits, at Williams College.

Methods

Participants

The online survey was completed by 259 Williams College students. Participation in this study was voluntary and anonymous. Each student in a 200-level Williams Psychology class conveniently sampled 5-10 participants for the study; those participants' participation was voluntary, and there was no incentive included. The remaining portion of volunteers were recruited from an entry-level psychology class; an incentive (extra credit for the class) was included to bolster participation in the study.

Of survey participants who included their class year in the survey, there were 108 freshmen, 83 sophomores, 38 juniors, and 30 seniors. Two-hundred twenty-seven survey participants reported their family income in the survey. There were about 20 participants in each of 6 family income brackets, ranging from making under \$49,999 to making between \$150,000 and \$174,999; more than a third of participants (97) reported their family income as being \$175,000 or higher.

Materials and Procedure

Participants were first asked about rest, activities, food, and eating. Questions examined how many hours participants spent throughout the week resting (i.e., sleeping and relaxing, using a 12-point scale) and number of hours per day, on average, doing activities (i.e., homework, extracurricular activities, or time outside, each on a 10-point scale). There was also one question about when the individual goes to sleep (before 10 PM, 10 PM to 12 AM, 12 AM to 2 AM, or after 2 AM). Participants were also asked about their eating habits (i.e., satisfaction with their eating habits, healthiness of eating habits, effect of academic stress on eating habits, each on a 1-10 scale) and their campus dining preferences (i.e., how much they like each of 8 dining halls, on a 7-point scale).

Participants' demographics and background were also assessed. Participants were asked about their class year (and, if not a freshman, their GPA), their hometown (7 degrees of urban to rural), high school (6 types, e.g., private, public, boarding), household income (on an 8-degree scale), campus housing (i.e., which of 14 dorms they live in), and political orientation (5 degrees of very liberal to very conservative).

Results

The average number of hours the participants report resting per day was computed by summing the average number of hours the participants report sleeping on weeknights and the average number of hours the participants report relaxing per day. Participants' number of hours spent resting was positively and significantly correlated with how satisfied they are with their eating habits, on a scale of 1 being extremely dissatisfied and 7 being extremely satisfied ($r(257) = .14$, $p = .025$).

The entire sample slept about 7.1 hours per weeknight, on average. Furthermore, the analysis indicated that the more hours participants slept, on average, on weeknights was positively and marginally significantly correlated with how satisfied they are with their eating habits, on a scale of 1 being extremely dissatisfied and 7 being extremely satisfied ($r(257) = .12$, $p = .060$).

Participants' ratings of how healthy they feel they eat during an average week at Williams (on a scale of 1 being extremely unhealthy and 7 being extremely healthy) was positively and significantly correlated with how satisfied they are with their eating habits, on a scale of 1 being extremely dissatisfied and 7 being extremely satisfied ($r(257) = .39$, $p <.001$).

Participants who slept before 12 AM rated their satisfaction with their eating habits during the semester significantly better ($M = 4.31$) than participants who slept after 12 AM ($M = 3.94$) ($t(257) = 2.293$, $p = .023$). Participants who slept before 12 AM rated how healthy they feel they eat during an average week at Williams significantly better ($M = 4.25$) than participants who slept after 12 AM ($M = 3.84$) ($t(257) = 2.778$, $p = .006$).

Discussion

Consistent with previous research among college students, sleeping earlier and more is associated with healthier, and higher self-satisfaction with, eating habits among Williams students. Williams students in the study sleep an average of seven hours per weeknight. Those who slept before midnight were significantly more satisfied with their eating habits and the healthiness of their diet than those who slept after midnight. Participants who rest more (i.e., overall sleep more during the night and relax more during the day) tended to perceive their eating habits as healthier; those who sleep more reported higher satisfaction with their eating habits.

The study underscores the important relationship of relaxation and sleep with a healthy diet and greater self-satisfaction with one's diet. By implementing resources and regulations that promote restful behaviors among students, campus administration can empower students to prioritize their mental and physical well-being. Increasing access to healthy sleep information to college students is linked to better sleep and healthy behaviors (Athey & Grandner, 2017); the College should consider implementing stress management workshops, meditation and mindfulness group sessions, and sleep hygiene (e.g., sleep schedule, caffeine, exercise) informationals. Other potentially supportive recommendations include designating more relaxation spaces on campus where students can take short breaks or naps during the day, providing items (e.g., eye masks, blackout curtains) to help students make their dorms more sleep friendly and encourage earlier sleeping times, and increasing access to discrete mental health services for students experiencing sleep-related issues or stress.

In this highly academic, rigorous, liberal arts college, prioritizing physical and mental health is crucial for fostering academic excellence, resilience and adaptability, personal fulfillment and happiness, creativity, and social connections. Embracing a holistic approach to student well-being aligns with the ethos of a liberal arts education: emphasizing the development of the whole person and preparing students for success both academically and in life beyond college.

A number of important questions related to the hypothesis remain to be explored. Now that the association between better rest and better eating habits has been established, the causal relationship(s) between them should be investigated. As this study relied on retrospective report, which is subject to recall bias (Crochiere et al., 2021), follow up studies on health behavior at Williams should consider utilizing momentary data collected by ecological momentary assessments (EMAs; brief, self-report surveys that are completed frequently in one's natural environment) and sleep/activity sensors.

Due to the sampling method, certain characteristics, such as the distributions of class years and of income brackets, are skewed. For example, the distribution of class years is skewed right because more underclassmen chose to and/or got a chance to participate in the study. Among other effects, this may have led to an inflated average number of hours of sleep per night used in our analyses (e.g., underclassmen may have lighter workloads and thus more hours in the day to sleep). To have a sample more representative of the Williams student population, future iterations of the study should utilize random sampling to recruit participants.

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Author's Note

Thank you to Professor Steven Fein for his invaluable assistance to this project and paper.

Investigating the Kinetics and Regioselectivity of a 1,3-dipolar Cycloaddition using NMR Spectroscopy, GC-MS, and *In Silico* Orbital Analysis

Alex Cumming

Abstract

Here we investigate the regioisomerism of a 1,3-dipolar cycloaddition and the effects of para-dipolarophile substituents on rate. Reaction products were analyzed using ^{1}H-NMR and GC-MS, and rate data was collected using a ^{1}H-NMR pulse program to collect multiple 1D spectra over time. Electrostatic and orbital energy data were also gathered *in silico* using Spartan software. We observed exclusive formation of 3,5-diphenyl isoxazoline products in accordance with computationally predicted electrostatics of participating atoms. Even though dipolarophiles with more electron-withdrawing groups had decreased orbital energy gaps to a consistent dipole, we observed a decrease in reaction rate for dipolarophiles with greater electron-withdrawing character. Our upside down V-shaped trend on the Hammett rate plot may indicate a changing mechanism for the cycloaddition between electron-donating and electron-withdrawing substituents.

Introduction

A well-known synthetic method of forming heterocycles is the 1,3-dipolar cycloaddition, also known as the Huisgen reaction after the chemist who first presented it.[1] In this type of reaction, a three-membered dipole contributes 4 π-system elections and a two-membered dipolarophile contributes 2π electrons to combine to form a five-membered ring. One specific 1,3-dipolar cycloaddition involves the generation of a dipole from a readily available oxime in the presence of bleach.[2] Combined with readily available alkene dipolarophiles, a five-membered ring is formed.[2] With styrene, two regioisomers may be formed; Gingrich and Pickering[2] reported that these isomers can be distinguished by 1H-NMR spectroscopy but did not detail the ratio in which they are formed. The kinetics of the reaction can be studied at low concentrations in the presence of a liposome membrane.[3] Svatunek et al.[4] and Dones et al.[5] have more recently found ways to accelerate the rate of 1,3-dipolar additions through stabilization of the dipole by F- ions[4] and reactant-reactant hydrogen bonding.[5]

In our experiment, we investigated substituent effects on the rate of the 1,3-dipolar addition originally demonstrated by Gingrich and Pickering.[2] We sought to understand how various electron donating and withdrawing substituents affect the rates of these cycloadditions. After trying a variety of spectroscopic techniques, we settled on using pseudo-2D NMR spectroscopy as the most reliable method to gather concentration data for use in kinetics analysis. We also relied on NMR spectroscopy to verify product formation and explore the regioselectivity resulting in possible 3,4- and 3,5-diphenyl isomers.

Formation of a 3,5-diphenyl isomer was favored exclusively for both styrene and 4-chlorostyrene, and can be expected for other substituted styrenes due to electrostatic trends. Kinetic data was acquired by preserving the activated dipole in deuterated chloroform ($CDCl_3$) at concentrations used by Iwasaki et al.[3] and taking multiple 1D NMR spectra over time. Increasing substituent σ value may increase reaction rate up to a point, then decrease it as substituents become more electron-withdrawing.

Experimental Methods

NMR

We collected NMR spectra using a Bruker 500 MHz spectrometer and TopSpin software. Data was processed via Fourier transform analysis. Samples were dissolved in CDCl3 containing 0.03% TMS (Sigma-Aldrich).

Gas Chromatography–Mass Spectrometry (GC-MS)

Spectra were collected on an Agilen 890 GC-MS and were analyzed using Agilent Masshunter software.

GC Peaks were analyzed with Masshunter software.

Investigating Reaction Kinetics using GC-MS

Reactions for kinetic studies were run according to the procedure found in Gingrich and Pickering.[2] Anisole (25 µL) was added to the reaction mixture as an internal standard for GC. Approximately 5 drops of the reaction mixture was removed from the test-tube every 6 minutes, and then extracted with ethyl acetate to remove any water from the sample. The test-tube was vortexed using a benchtop vortexer everytime a sample was removed from the test-tube to recombine the aqueous and organic layers prior to sample removal. The organic ethyl acetate layer (100 µL) was diluted with CH_2Cl_2 (1 mL) in a GC-MS vial for further analysis.

Cycloaddition Reactions

We added 2.27 mmol of benzaldehyde oxime (BO) and three drops of triethylamine (TEA) to 1 mL of DCM to perform the dipole-dipolarophile additions according to Gingrich and Pickering.[2] We also prepared the BO and TEA in chloroform ($CHCl_3$) to explore whether the reaction could be run in a more readily available solvent for NMR spectroscopy. Then, we added an excess (8.73 mmol) of styrene, chlorostyrene, or acetoxystyrene to the reaction mix. To this solution we added 6 mL bleach (NaClO) in 2 mL aliquots with vortex mixing and cooling in between additions. After one hour of mixing every six minutes at room temperature, we rotovapped the reaction mix and left products one week to dry. We then recrystallized using Gingrich and Pickering's[2] recommendation for ethanol as a recrystallization solvent.

Reaction Product Quantifications

δ = chemical shift (ppm); s = singlet, m = multiplet, dd = doublet of doublets; #H indicates relative integration. t_r = retention time; *m/z* = mass-to-charge ratio for molecular ion; all GC-MS runs were performed using ethyl acetate (EtOAc) as solvent.

Product from styrene. ^{1}H-NMR δ 7.71 (s, 2H), 7.40 (m, 7H), 7.07 (s, 1H), 5.79 (dd, 1H), 3.83 (dd, 1H), 3.40 (dd, 1H). GC-MS (EtOAc): t_r 13.19 min, *m/z* 223. Expected *m/z* 223. Product from chlorostyrene (crude). GC-MS (EtOAc): t_r 14.26 min, *m/z* 257. Expected *m/z* 257. Product from acetoxystyrene (crude). GC-MS (EtOAc): t_r 15.30 min, *m/z* 281. Expected *m/z* 281.

Investigating Reaction Kinetics Using NMR

We scaled down the reaction volume from Gingrich and Pickering[2] by a factor of 16 (mmol scale) in order to run it in a 5 mm NMR tube for possible NMR application. The instrument failed to lock onto the sample, preventing further exploration. Extracting the active BO dipole and TEA into $CDCl_3$ (as performed by Iwasaki et al.[3] into propanol) and adding this mixture into the NMR tube allowed us to successfully measure kinetics by running a ^{1}H-NMR pulse program (Td-30, D20-60 sec, NS-4) and create a pseudo-2D NMR dataset.

Investigating Reaction Kinetics Using UV/Vis

We attempted to replicate the UV/Vis kinetics measurements performed by Iwasaki et al.[3] with styrene instead of the authors' original maleimide. We performed the cycloaddition reaction in 1-propanol and reduced reagent concentrations to fit within the absorbance profile of the spectrophotometer. Failure to detect a change in λ_{max} or in absorbance at λ_{max} of our product (265 nm) prevented us from performing further experiments.

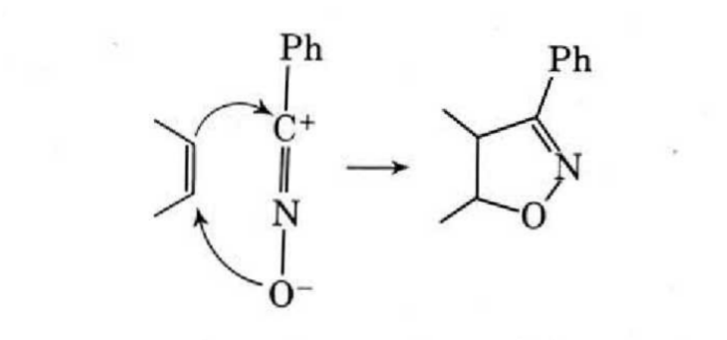
Computational Analysis

We used Spartan '20 software to calculate HOMO-LUMO gaps between the dipole and dipolarophile reactants. Calculations were performed using the Hartree-Fock method and the 6-31G* basis set.

Results and Discussion

Bulk Reaction and Product Analysis

We investigated the product and kinetics of the 1,3-dipolar addition described in Gingrich and Pickering[2] (Scheme 1). Their original reaction involved activating benzaldehyde oxime with bleach (NaClO) as the dipolar nucleophile and cis or trans stilbene and styrene as the dipolarophile. For styrene, two regioisomers may form, a 3,4-diphenyl or a 3,5-diphenyl isoxazoline (Figure 2). Our initial investigations focused on (1) identifying the regioisomers of the products and (2) determining whether the reaction, which was originally run in dichloromethane (DCM), could also be run in chloroform for potential kinetics applications using a more readily available ^{1}H-NMR solvent.



Scheme 1: 1,3-dipolar cycloaddition reaction from Gingrich and Pickering.[2] We modified the alkene dipolarophile of this 1,3-dipolar cycloaddition, investigating substituted styrenes rather than 2-butene (see Figure 2).

While running the reaction in bulk with styrene as the dipolarophile, we observed a light-green colored aqueous top layer and a cloudy organic bottom layer (Figure 1). This observation was the same whether the reaction was run in DCM (following Gingrich and Pickering's[2] procedure) or chloroform. When running the reaction with acetoxystyrene and 4-chlorostyrene, the solutions were beige and light-green, respectively (Figure 1). Though chloroform (D=1.49 g/cm^3) and DCM (D=1.33 g/cm^3) are both more dense than water, our original styrene product was likely residing in a colored organic top layer since in both cases the top layer's volume (~2mL) was less than that of the aqueous layer (~6mL). Our bulk reactions for chlorostyrene and acetoxystyrene were more ambiguous, forming colored suspensions. This difference in appearance was likely due to reagents and products containing the additional chloro/acetoxy groups being more soluble due to the additional polar bonds/regions. The end goal of these reactions was product isomer analysis, and in all cases we were able to isolate sufficient product for analysis.

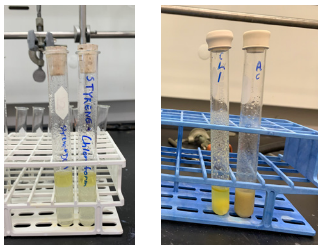


Figure 1: Images of (left to right) reactions of activated benzaldehyde oxime with styrene dipolarophile in DCM; styrene dipolarophile in chloroform; 4-chlorostyrene dipolarophile in DCM; and 4-acetoxystyrene in DCM. Despite differences in appearance, all reactions yielded sufficient product for NMR analysis and product confirmation.

Depending on the regioselectivity of the reaction, a 3,4-diphenyl or 3,5-diphenyl isomer may be observed (Figure 2). Gingrich and Pickering[2] did not specify which isomer is formed but suggested that product NMR would be useful for structure assignment. Following our bulk reactions, we purified our product formed with a styrene dipolarophile by recrystallization in ethanol.[2] Recrystallization yielded small white crystals from which we obtained an NMR spectrum (Figure 3). The predicted peaks for the 3,5-diphenyl product matched our spectrum more closely than the peaks for the 3,4-diphenyl isomer (Figure S1) indicating that the reaction had formed the 3,5-diphenyl structure. The hydrogen(s) adjacent to the oxygen of the ring will be the most downfield after the aromatic protons, and only one H is observed with our product at δ 5.79 ppm (Figure 3). This methine proton experiences deshielding from the neighboring oxygen atom and the aromatic phenyl group. For the 3,4-diphenyl isomer, we would expect two H in this region with one upfield, but instead we observe that one H at δ 5.79 ppm and two H in the at δ3-4 ppm region, pointing towards the 3,5-diphenyl isomer. These upfield peaks are found at δ 3.84 (dd, 1H) and δ 3.40 (dd, 1H); we observe two peaks because the product is diastereotopic with a stereocenter at carbon 5 and the adjacent H are in different chemical environments relative to the phenyl group on that carbon.

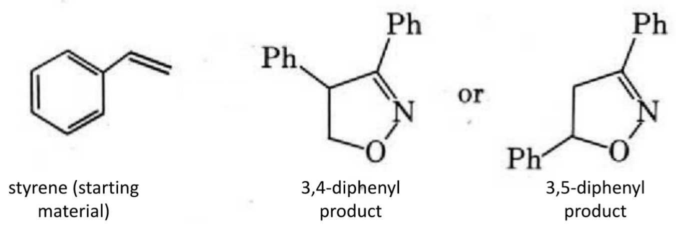


Figure 2: The possible 3,4-diphenyl and 3,5-diphenyl isomers (center and right structures, respectively) formed from the 1,3-dipolar cycloaddition with styrene (left structure) as the dipolarophile.

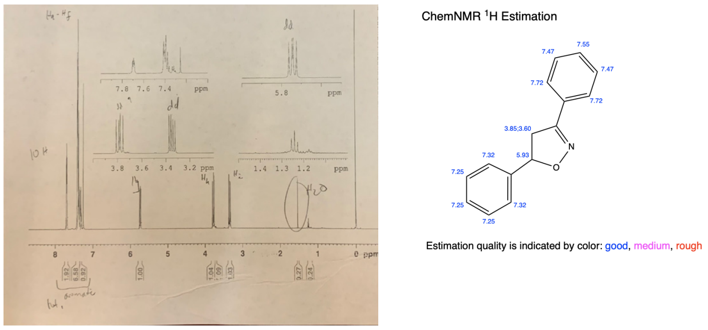


Figure 3: NMR spectrum (left) and ChemDraw depiction with predicted NMR chemical shifts (right) of our 3,5-diphenyl product from styrene cycloaddition. The predicted peaks generally match our spectrum.

A similar NMR spectral analysis of recrystallized product from our 4-chlorostyrene cycloaddition revealed that the 3,5-diphenyl isomer was exclusively formed (Figure 5). In this case, we report an NMR spectrum of crude product. The lack of recrystallization resulted in several starting material peaks in the spectrum. Nonetheless, our peaks match those predicted for the 3,5-diphenyl isomer, indicating it is likely exclusively favored here as well. Once again, we observe one relatively deshielded product H in the δ 5-6 ppm region (roughly, due to starting material presence), rather than two; and two product H in the δ 3-4 ppm region, matching the distribution of our 3,5-diphenyl product from styrene. It is possible that the steric hindrance of the phenyl rings prevents formation of the 3,4-diphenyl isomer, but more data would be required to confirm our hypothesis. Replacement of one or both phenyl groups with hydrogen atoms or other smaller groups followed by reaction and product structure analysis could inform us as to whether steric effects are a determining factor for this cycloadditon's regioselectivity.

We also found an electrostatic reason for the observed regioselectivity. Analysis in Spartan showed that the reacting C(H_2) of styrene is more negatively charged than the reacting C(H) (Table S1). The mechanism leading to the 3,5-diphenyl product matches this observation, since the more negative region of the dipolarophile would approach the positive carbon of the dipole, and the less negative region of the dipolarophile would be approached by the negative oxygen of the dipole (Figure 4).

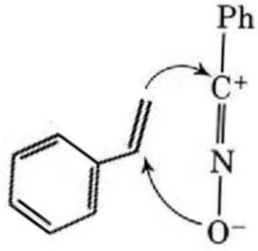


Figure 4: Reaction mechanism showing hypothetical proximity of styrene CH_2 to benzaldehyde oxime C and benzaldehyde oxime O to styrene CH.

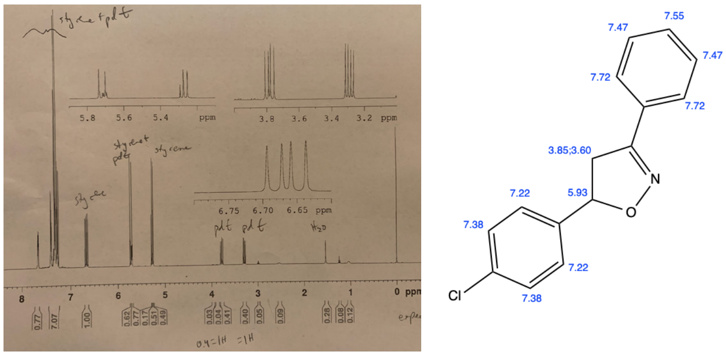


Figure 5: NMR spectrum (left) and ChemDraw depiction with predicted NMR chemical shifts (right) of our 3,5-diphenyl product from chlorostyrene cycloaddition. The predicted peaks can be found on our spectrum, as well as starting material peaks.

We also performed GC/MS analysis on our styrene addition product. The gas chromatograms included two significant peaks with retention times at 4.4 min and 13.2 min. The gas chromatogram and mass spectra were the same regardless of whether the reaction was performed in DCM or chloroform (Figure 6). Following analysis of their mass fragmentation patterns in the corresponding spectra, we identified these peaks as styrene and product, respectively (Figure 7). Our GC/MS data further support successful product formation that matches the 3,5-cycloaddition product. GC-MS analysis of our 4-chlorostyrene and acetoxystyrene bulk reactions confirmed that they formed the expected product, at least according to molecular weight (Figure 8). Collectively, these NMR, Spartan, and GC-MS findings confirm that the reaction proceeds according to the predictions in Gingrich and Pickering[2] and that the 3,5-diphenyl isomer is exclusively formed.

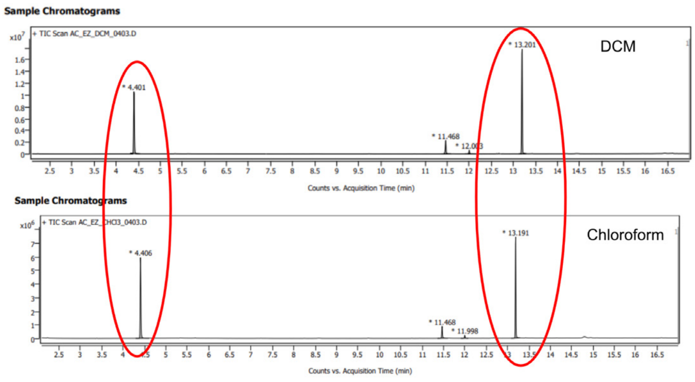


Figure 6: Chromatograms for crude product from styrene cycloaddition reactions in DCM and chloroform. As shown by the red circles, solvent choice between these two did not affect the formation of product. The small peaks at 11.5 min and 12.0 min are likely column debris, since the mass spectra contained large molecular ions that did not match the molecular weight of any of our reactants.

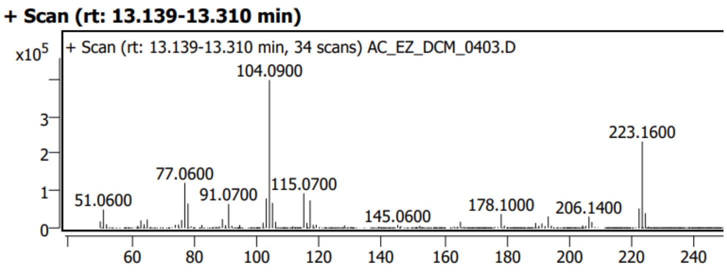


Figure 7: Mass spectrum of the product peak at 13.2 min. Our expected product molecular weight of 223 g/mol matches the *m/z* ratio of the mass ion in this spectrum, indicating that it corresponds to our styrene addition product.

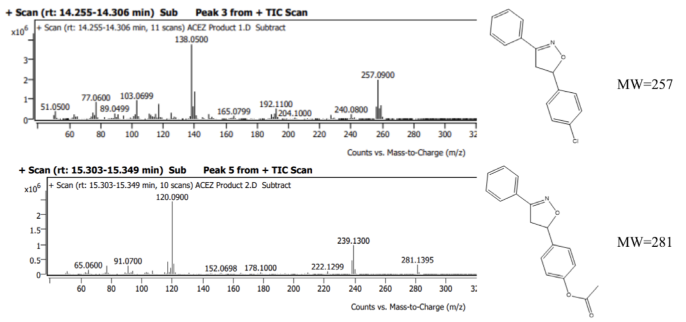


Figure 8: Mass spectra and structures with molecular weight of our 4-chlorostyrene and 4-acetoxystyrene products.

Kinetics and Rate Constants

Before settling on using NMR spectroscopy to acquire kinetics data, we attempted to measure reaction kinetics using UV/Vis spectroscopy as shown in Iwasaki et al.[3] and GC-MS. Although we could measure absorbance spectra for starting material and product, we were unable to detect a change in λ_{max} over time for our reaction, nor did we find a significant change in intensity at 265 nm (λ_{max} for our product) over time. We likely ran into this difficulty because styrene had a high absorbance at 250-260 nm that may have obscured an intensity change in the product peak. For future experiments, we would use the dipolarophile from Iwasaki et al.[3] which absorbs in the visible range and ideally would allow us to accurately measure increasing product absorbance over time.

We also performed GC-MS on samples taken at regular time points from a bulk reaction with styrene as the dipolarophile and found that the relative integrations of product and anisole peaks did not appear to change over time (Figure 9). The fact that these peaks had reached a final integration value informed us that the reaction was likely occurring very quickly. It is also possible that the cycloaddition was continuing in the DCM solvent used for GC-MS; either way, the reaction ran effectively to completion before we could gather kinetic data using GC-MS.

In an attempt to more clearly measure the kinetics of the reaction, we repeated the styrene bulk reaction with some changes to sample collection. Performing a mini-extraction at each time point and immediately placing samples on ice gave strong trends for product formation as measured by GC relative to anisole and styrene peak integrations (Figure 10). Following this successful capture of changing relative amounts of product and starting material relative to anisole, we attempted an acetoxy bulk reaction with the same method of sample collection and an anisole reference peak. Unfortunately, our gas chromatogram was messy (Figure S2) and we were unable to find peaks with significant change in integration over time.

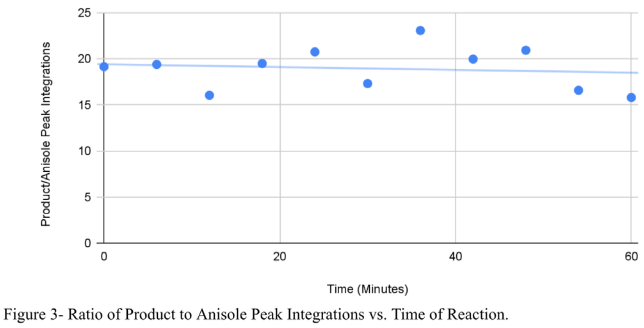


Figure 9: Graph showing the ratio of product:anisole peak integrations versus time since reaction start. There is no relationship between time and product/anisole peak integration for this bulk reaction.

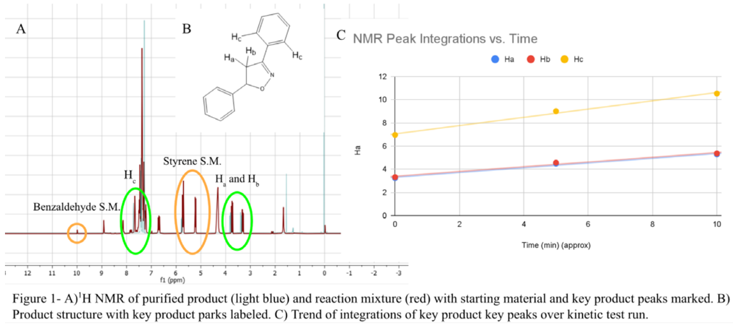


Figure 11: A) Representative ^{1}H NMR spectra of purified product (light blue background) and reaction mix (red). B) Structure of product with significant H atoms labeled. C) Graph showing increasing trend of product peak integrations over time.

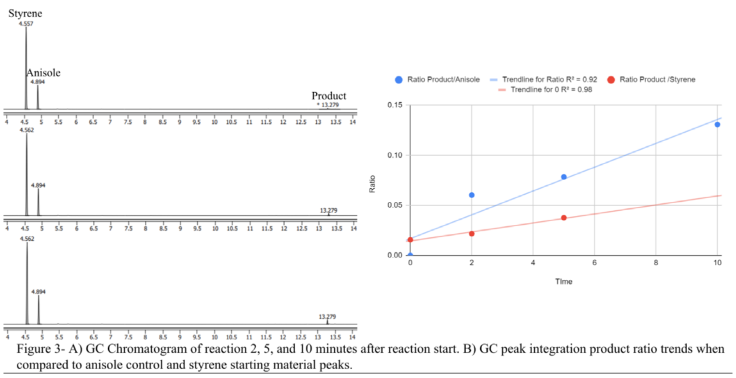


Figure 10: Gas chromatograms for samples taken from the cycloaddition with styrene 2, 5, and 10 minutes after reaction start (left). Graph showing an increasing ratio of product:anisole and product:styrene peak integrations over time (right).

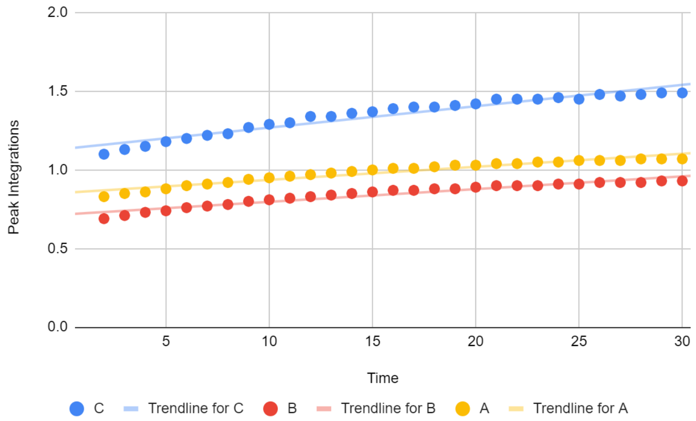


Figure 12: Graph showing increasing peak integrations for three different hydrogen atoms on the acetoxystyrene product. The hydrogen atoms of interest are equivalent to H_a (yellow), H_b (red), and H_c (blue) on the styrene product (Figure 11).

Following this finding, we further investigated NMR spectroscopy as a method for capturing kinetics data. Taking aliquots and making sure that the reaction was quenched would have been much more labor intensive than running the reaction in an NMR tube while collecting spectra over time. Running the reaction with active dipole in $CDCl_3$ allowed us to successfully take three spectra for a reaction with styrene showing changes in product peak integrations over time (Figure 11). Next, we collected NMR spectra of a run using acetoxystyrene over a full time frame from the combination of reactants to 30 minutes (Figure 12). These data also showed an increasing trend in product peak integrations over time, confirming that we could calculate rate constants using NMR spectra over time.

Comparing product peak integrations to the integration of the TMS peak with a known number of protons in the sample allowed us to calculate the changing concentration of product over time and calculate rate constants (Table 1). Our reactions are pseudo-first order since we included a large excess of dipolarophile (styrene or substituted styrene) into each reaction. We also calculated pseudo rate constants based on changing peak integrations rather than concentrations because the peak of interest overlapped starting material peaks in cyanostyrene.

We used our pseudo rate constants to produce a Hammet plot (Figure 13). Using concentration-based rate constants produced a similar plot (Figure S5), so we used the pseudo rate constants to include our data point for cyanostyrene. Based on our ρ value of -0.194, it appears that electron-withdrawing group (EWG) substituents reduce the rate of the reaction and that electron-donating group (EDG) substituents increase the rate. This finding differs from our prediction that EWG substituents would increase the rate of the reaction based on styrene's role as the dipolarophile. One possible explanation for this observation is that, though EWG contributed favorably to the electrophilicity of the dipolarophile, they also deactivated the 2π electrons participating in the cycloaddition and therefore decreased the overall rate. By altering the method of dipole activation following Iwasaki et al.,[3] scaling down the reaction, and running it in $CDCl_3$ (an alternative solvent to the original from Gingrich and Pickering[2]), we successfully captured rate data and used it to form trends with substituent σ values.

Dienophile	σ Value	*k*
Styrene	0	4.47×10^{-4}
Methylstyrene	-0.17	8.70×10^{-4}
Chlorostyrene	0.23	7.93×10^{-4}

Table 1: Rate constants (*k*) for the cycloaddition using various substituted styrenes. Rate constants are calculated using concentrations of product according to integration relative to the known quantity of TMS. See supporting information for an example graph and equation.

Dienophile	σ Value	*k*
Styrene	0	7.64×10^{-4}
Methylstyrene	-0.17	9.68×10^{-4}
Chlorostyrene	0.23	1.18×10^{-3}
Cyanostyrene	0.66	6.74×10^{-4}

Table 2: Pseudo rate constants for the cycloaddition using various substituted styrenes; these constants were calculated using ln[1/product peak integration] since the cyanostyrene product peak we have been using overlaps starting material peaks and is therefore not a reliable measure of concentration. See supporting information for an example graph and equation.

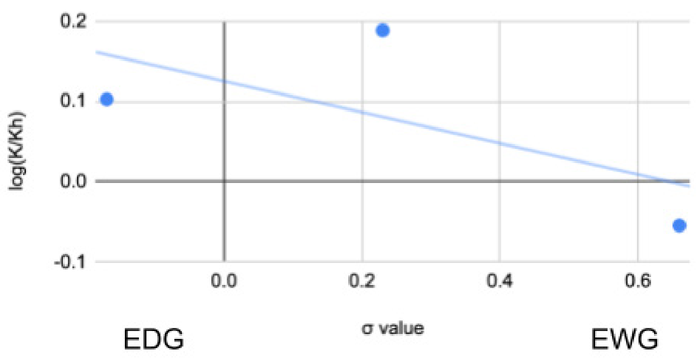


Figure 13: Hammett plot comparing σ value of substituents to log(Kr/Kh) using pseudo rate constant values for methylstyrene, chlorostyrene, and cyanostyrene. EWG substituents appear to reduce the reaction rate, ρ = -0.194 with $R^2 = 0.427$. Kr = rate for substituted reactant; Kh = rate for styrene.

HOMO/LUMO Gap Analysis and Comparison to Rate Data

To further explore the mechanism affecting rate, we analyzed Highest Occupied Molecular Orbital-Lowest Unoccupied Molecular Orbital (HOMO-LUMO) energy gaps in Spartan. Our *in silico* analysis indicated that more EWG substituents decrease the HOMO-LUMO energy gap between our dipole (activated benzaldehyde oxime) and dipolarophile (styrene or substituted styrene) (Figure 14). In contrast, EDG substituents appear to increase the gap. This trend makes sense since our 1,3-dipolar cycloaddition involves the HOMO of the dipole (benzaldehyde oxime) overlapping the LUMO of the dipolarophile (styrene or substituted styrene). EWG substituents on styrene generally lower the energy of the LUMO, decreasing the energy gap between its LUMO and the HOMO of our benzaldehyde oxime.

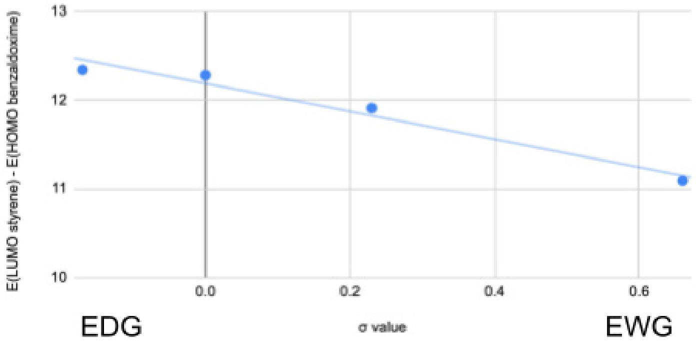


Figure 14: Hammett plot comparing σ value of substituents to the HOMO-LUMO energy gap between our starting benzaldehyde oxime and styrene or substituted styrene. EWG substituents appear to lower the energy gap, compared to EDG substituents which raise it.

These findings conflict with our Hammett plot for rate versus σ value (Figure 13). We expected that rate would increase as HOMO/LUMO gap decreased, but the rate appears to decrease according to our data points. It would be useful to replicate the point for cyanostyrene (σ = 0.66) since it is the one causing the regression to have a negative slope, which conflicts with the positive correlation we expected between rate and σ value. However, it is possible that this point is correct, since substituents on the dipolarophile of our reaction have been shown to increase then decrease rate in a V-shaped Hammett plot similar to ours.[6] Following similar cycloaddition reactions, Holman et al.[6] propose a radical pathway and changes in orbital interactions that might account for this difference in rate trend between EDG and EWG. We have documented an increasing-then-decreasing effect of substituent σ value on reaction rate; replication of our data would confirm this trend, which matches one found in the literature for a similar reaction.[6]

Activated Dipole Investigation

According to Iwasaki et al.,[2] the dipole stays activated in solution for at least 3h, and the authors used it within that time frame. We had leftover dipole in $CDCl_3$ from one week and used NMR spectroscopy to investigate whether the dipole remained activated over this longer time frame. We observed an absence of a significant peak at δ 8.2 ppm expected from inactive dipole starting material (Figure 15); this finding seemed to indicate that our dipole was still activated after one week. We compared the spectrum of the week-old dipole to a spectrum of freshly prepared dipole (Figure 16) and saw even less of a peak at δ 8.2 ppm, though in both cases the peaks were relatively small. These findings contrasted with the NMR spectrum of our starting material benzaldehyde oxime (Figure S6) which did indeed have a significant peak at δ 8.2 ppm. Unfortunately, in contrast to our NMR findings, reactions with week-old dipole did not run, suggesting that other chemical changes are likely occurring that render the dipole unusable for our reaction.

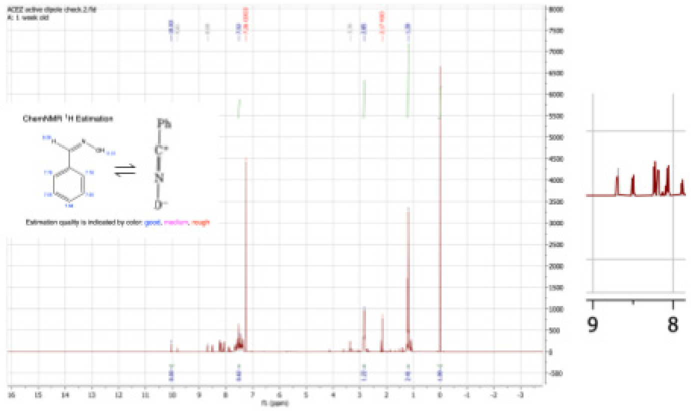


Figure 15: ChemDraw structure and predicted 1H chemical shifts (left of equilibrium), structure of activated dipole from Gingrich and Pickering[2] (right of equilibrium), and ^{1}H NMR spectrum for activated dipole in $CDCl_3$, one week after activation. There is a very minimal peak at δ 8.2 ppm, suggesting that the dipole is mainly in its active form, which lacks a peak there.

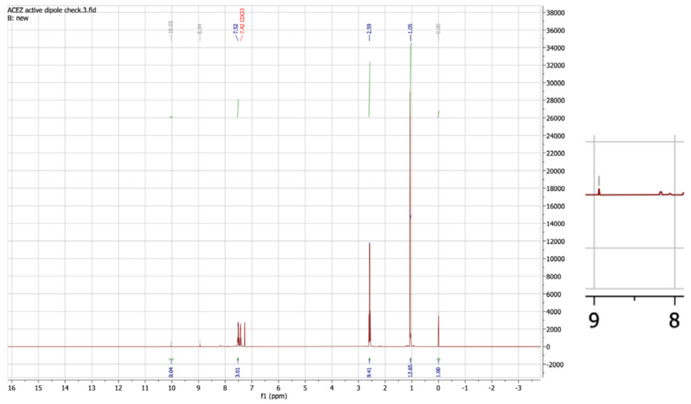


Figure 16: ^{1}H NMR spectrum for newly activated dipole in $CDCl_3$. There is virtually no peak at δ 8.2 ppm, suggesting that the dipole is completely in its active form.

Conclusion

We originally set out to study the regioselectivity of the 1,3-dipolar cycloaddition detailed by Gingrich and Pickering,[2] as well as investigate substituent effects on its rate. Using NMR and GC-MS, we were able to determine that the 3,5-diphenyl isomer was exclusively formed. Computational analysis offered an electrostatic explanation regarding the regioselectivity. After trying UV/Vis spectroscopy and GC-MS as methods for measuring reaction kinetics, we settled on ^{1}H-NMR for its precision and relative ease. Our kinetics data for styrene and substituted styrene as our reaction dipolarophile generated a trend that contradicted our expectations: here, we found an upside-down V trend that averages to a decreasing rate as substituents become more electron-withdrawing. Even though further computational analysis showed that EWG substituents decrease the HOMO-LUMO gap of the reaction, a change in reaction mechanism and orbital interactions[6] may be causing this nonlinear pattern. Future experiments using EWG and EDG with σ values between -0.17 and 0.66 (the range that we studied) could further inform this trend and allow us to more precisely locate the σ value at which the mechanism's orbital interactions may be changing. In addition, repeating the reaction with substituents with σ values outside of this range would be useful for verifying that the V-shaped trend holds true for groups with more extreme electronic characteristics.

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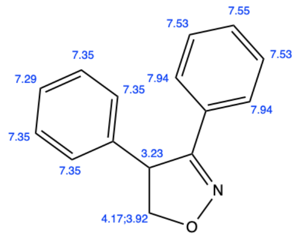
Appendix

ChemNMR ^{1}H Estimation



Estimation quality is indicated by color: good, medium, rough

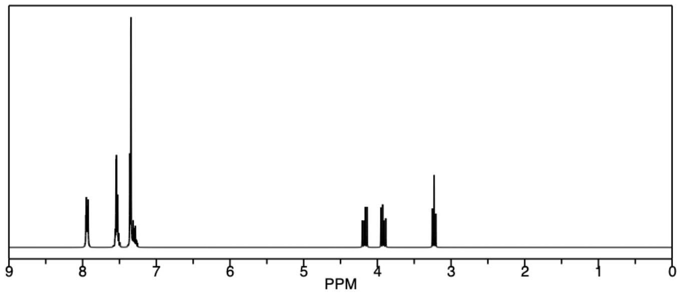


Figure S1: Structure and predicted NMR spectrum of the 3,4-diphenyl isomer of our styrene addition product.

Molecule	Atom	Charge
Dipole (benzaldehyde oxime)	C	-0.272
	O	-0.506
Dipolarophile (styrene/substituted styrene)	$C(H_2)$	-0.432
	C(H)	-0.239

Table S1: Electrostatic values from Spartan for reacting atoms. These data support our regioselectivity observation that the two molecules react in a way that favors bringing together opposite charges.

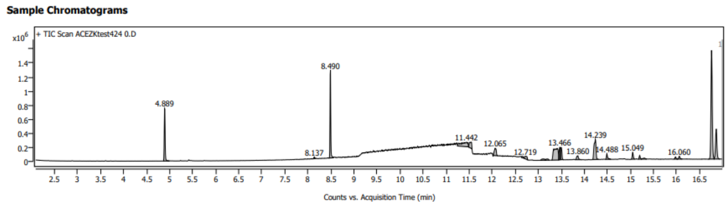


Figure S2: Representative gas chromatogram from a sample taken during our acetoxy bulk run. We were unable to find the peak changes necessary for acquiring kinetics data in these chromatograms.

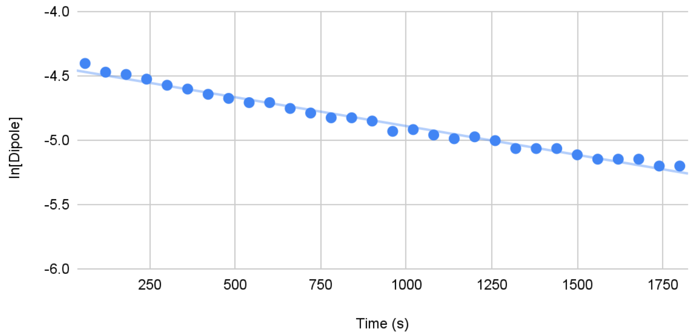


Figure S3: Rate plot for styrene; k = -4.47x10^{-4} M/s was calculated from ln[styrene] versus time.

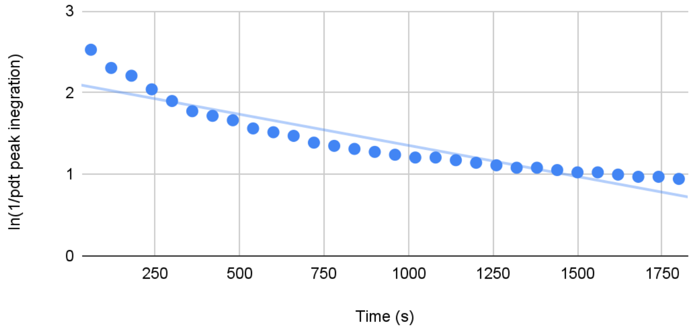


Figure S4: Pseudo rate constant plot for styrene;
k = -7.64x10^{-4} M/s was calculated from ln[styrene] versus time.

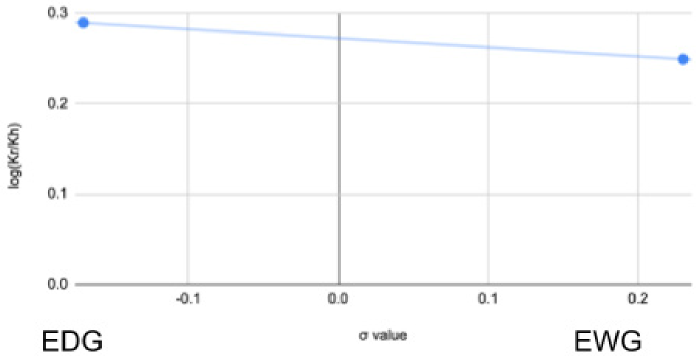


Figure S5: Hammett plot comparing σ value of substituents to log(Kr/Kh) using rate constant values for methylstyrene and chlorostyrene. EWG substituents appear to reduce the reaction rate, ρ = -0.101. Kr = rate for substituted reactant; Kh = rate for styrene.

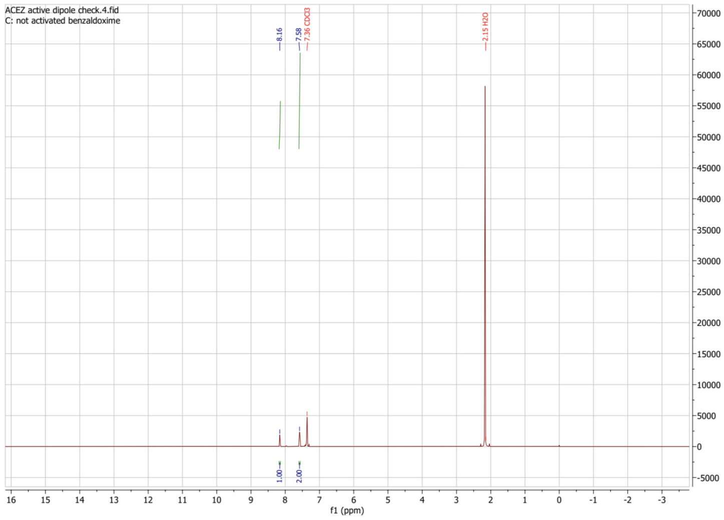


Figure S6: ^{1}H NMR spectrum of our benzaldehyde oxime starting material with a peak at δ 8.2 ppm integrating to 1H.

WURJ