CASE WESTERN RESERVE UNIVERSITY

Discussions

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Discussions

The Undergraduate Research Journal of CWRU

VOLUME XIX, ISSUE I

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LETTER FROM THE EDITOR

Dear Reader,

Thank you for picking up this issue of Discussions: CWRU's undergraduate research journal. Your readership is paramount in our mission to empower students worldwide in their pursuit of organized curiosity. We understand that many undergraduate students encounter barriers when entering the structured world of academia and research. By reading and supporting this publication, you play a vital role in dismantling those barriers and granting access to the fascinating realm of research.

In addition to providing invaluable experience for our featured authors, Discussions plays a pivotal role in fostering a deep appreciation and understanding of research across all fields for our dedicated student team. Within these pages, you'll find interviews with esteemed faculty, stunning scientific illustrations, and thought-provoking debates on fundamental research questions all created and compiled by our incredible undergraduate staff.

This year, our amazing team has risen far above my expectations with great dedication and responsibility. It has made my role an absolute pleasure. I'd also like to extend special thanks to our staff mentor, Sheila Pedigo, for her years of unwavering dedication and guidance. While there are many others who have been quintessential to the success of this publication, it's impossible to name everyone: you know who you are.

As I prepare to depart from this beloved organization, I find it difficult to express just how grateful I am to this team for their patient, loyal, and unwavering support. These four years have been instrumental in my personal growth and have played a pivotal role in shaping who I am today. When I joined this organization as a freshman, I never anticipated that the world would be plunged into a devastating pandemic during my second semester, severely limiting our ability to publish and design our journals. That remote year tested the resilience of our organization, and it is thanks to the incredible upcoming leaders within the organization today that it continues to thrive.

While I am eagerly anticipating the transition into the professional world as an engineer, I will deeply miss this remarkable organization. I will forever cherish the person this organization has helped me become, and fondly reminisce whenever I remember my oxford commas.

I extend my heartfelt thanks to everyone who has supported my journey at CWRU and this incredible organization. I am so excited to watch everyone blossom in the upcoming years.

Sincerely,

Rebecca Wilcox
Editor-in-Chief

media board

SOURCE
SUPPORT OF UNDERGRADUATE RESEARCH AND CREATIVE ENDEAVORS

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AN INTERVIEW WITH

Dr. Christian Zorman

By Omar Ali

Dr. Chris Zorman is the associate Dean for research in the Case Western Reserve University School of Engineering and a professor in the Department of Electrical Engineering and Computer Science. His current research interests include microsystems and nanosystems.

This interview has been edited for length and clarity with Dr. Zorman's consent.

Photo: Credit: Dr. Christian Zorman

Q: Looking at your history, I see that your undergraduate and graduate degrees were in physics, but now you're a professor in engineering. Do you want to tell us a little bit about this transition?

A: Pretty early on, I decided I wanted to pursue a career in research, and at the time when I was an undergrad, it wasn't clear which direction to go in. I didn't have clarity. In fact, when I started as an undergrad, I was intending to become a lawyer. I actually have a BA in economics, which is kind of reflective of the fact that at one time I was an econ major with the idea of going to law school. But through influences from some of my closest friends who were engineering majors, I decided to make a pivot towards STEM. I was already in the College of Arts and Sciences for the economics degree, so it was kind of natural for me to pick physics over engineering since I had a lot of the general education requirements finished for the econ degree. I got an undergrad degree in physics, and then I decided, 'OK, I definitely want to do research." That came about through undergrad and work experiences, when I was an undergrad at Ohio State working at the Byrd Polar and Climate Research Center where I analyzed data on weather patterns over the Antarctic continent, and from working in the summers at a Nestle research facility in my hometown where I worked in food science. Obviously, I didn't go into food science and I didn't go into meteorology, but those experiences led me to a career in research. I still liked the physical sciences better, so I got a PhD in condensed matter physics here at Case. My dissertation was on surface science associated with diamond thin films, and when I graduated, this new field called micro-electromechanical systems (MEMS) was starting up. MEMS involved semiconductor materials like silicon, but instead of making electronics, which was the conventional way then, the field of MEMS involves the fabrication of mechanical structures from these semiconductor materials. I thought that looked like it was a promising area. It wasn't owned by any one discipline. You had electrical engineers working in MEMS. You had mechanical engineers working in MEMS. You had physicists, chemists, and chemical engineers, all working in MEMS. I thought, "that would be a good place to go." I did an extensive postdoctoral research experience here at Case in electrical engineering in the MEMS field. Then, when I decided to go into academia as a profession, and in particular at a research university like Case, I knew that it would probably be a better fit for me to be in engineering than in physics, so I pursued faculty opportunities in engineering. I had one in biomedical, one in electrical, and then a couple others in material science that I pursued at the time. Ultimately, Case made the best offer, so I decided to stay here.

Q: You had experience and academic work in both science and engineering. What do you feel are some of the similarities and differences between doing research and academic work in science as opposed to engineering?

A: I think research is research, right? Research involves the discovery of new information, new knowledge, and, in my case, experimentation. If you're in the pursuit of knowledge or information, whether it's science or engineering, it depends upon the starting point. From a scientific perspective,

"If you want to know where the action is, you make yourself active in all of these events where information is exchanged."

namely a physicist's perspective, the pursuit of knowledge is in fact, the principal endeavor. So you engage in research for that purpose– to learn new things. Engineers do the same thing, but there's an additional component to engineering-based research in that it's typically guided by the desire to learn something that may have, or at least has the potential for, practical application. Both research-oriented scientists and engineers apply the scientific method to gain new knowledge, but where they choose to do their research may depend upon whether they're engineers or scientists. The engineer looks at gaining new knowledge that might lead to new processes, new devices, new software, or something along those lines, whereas maybe a chemist or physicist would be in pursuit of new knowledge for knowledge's sake, and that knowledge could then be utilized by research engineers to make new things. They're pretty close-coupled, and in fact, in the most interesting research areas, even in ones that you would classify as heavily weighted towards science, that research doesn't happen without engineers participating. And, on the flip side, in research that is oriented heavily towards engineering, practical applications don't happen unless there is participation by scientists. We often say in engineering that we're engaged in engineering science when we're talking about our research, so it's kind of a blend of both.

Q: Speaking of the scientific method and approaching open problems, how do you approach difficult and open problems in your work as a researcher??

A: I guess the first step is to discover what the problems are. Generally, if you're engaged in your scientific or engineering community, the problems of the day are widely discussed through conference participation, journal publications, conference publications, meetings, and seminars. If you want to know where the action is, you make yourself active in all of these events where information is exchanged. There are problems put out by companies, governments, and foundations. There's no lack of challenges and problems available for scientists and engineers to address and solve. Once you get motivated by one, you develop a plan to address that problem, and for faculty at universities like Case, we need to seek funding for the problems that we want to solve. We write proposals in which we clearly articulate the issue, the reason why that issue is important to solve, and we develop a research plan that will address that issue in some way or form along with the resources needed to do that. That involves specifying the equipment, time, and personnel, including graduate students and undergraduate student research assistants, and so on and so forth.

So that's what you do to develop a plan. If it's going to be funded by the federal government, it's often subject to peer review. Your ideas have to pass muster as they're evaluated by experts in your field.

How do I find these ideas? Usually in a place like Case, I have colleagues who are also looking to solve problems and I may be one who has a problem that I'm interested in solving, and I seek collaborators, or more often than not, because I'm a device developer, I have colleagues that have vexing problems that merit solving, and they're looking for those who can help develop the techniques and tools that may help solve that problem or perform the research.

Since I'm a device developer, I'm somewhat sought after when there are colleagues that realize they could use a device that does this, or a process that does that.

Before I move on, I don't want people to think that we're engaged in a service activity. For me to be excited about it, there has to be something new or novel about the device design or the materials that will go into whatever device we're going to make so that we're furthering knowledge in terms of device technology while simultaneously addressing a problem that might have scientific merit.

Q: Looking at your record, you've worked with physicists, biomedical researchers, and materials scientists and engineers. What are some reflections upon your experiences of working in different and unfamiliar disciplines, from the point of view of device making?

A: A long time ago, when I was a newly minted PhD, we would make a device just for the sake of making a device, to prove that we could make something that hadn't been made before– like a rotating disc on the microscale or a flexing beam on the nanoscale. You didn't really have to have an application picked out for that because those kinds of structures had not

yet been made at the dimensions that we were making them. We were engaged in an activity to show potential, and those were really exciting times because you could just think of something that hadn't been made and make it. MEMS has matured, and it has matured rapidly. In fact, some of the chips that make your phone sensitive to position, angle, and tilt are gyroscopes or accelerometers that are made using MEMS technology.

The field has advanced to making commercial products, which means a lot of the research issues that were identified early on had been solved. For folks like me that work in the device area, we have to now find compelling applications where MEMS technology could be a key approach to solving a problem, so I need collaborators. The collaborators will provide for me and my group the technical specs for a device that has purpose. As opposed to a device for "devices sake," we have to have a device made for "purpose's sake."

I need a broad base of collaborators, as you pointed out. I have collaborated with biomedical engineers, with aeronautics engineers, and many more. Material scientists are important collaborators for me because part of my research is to identify materials that haven't yet been used in micro devices, but might have really compelling properties that might make significant advancements in micro device tech, and we want to figure out how to get those materials into a micro device. Often, there are serious challenges associated with materials, such as compatibility or processability.

> "There are two different vocabularies, two whole different dictionaries even, when you're talking to a clinician than if you're talking to somone like an aerospace engineer."

You have to ask, if you are going to process it, are you going to lose the properties that you might have measured in bulk? Do the processing conditions change the properties of the material as you're making a device? Is the material compatible with the other materials in the device? These are the kinds of challenges that excite me and the people in my group. We're often looking for collaborators who have identified areas where microdevice technology could be a key enabling tech, but you have to make devices from non-conventional materials to make it happen.

Q: Is there often a learning overhead?

A: Sure. When you work within an engineering domain, it's not so challenging. Engineers may not use the same vocabulary, but they speak a common language. But if you go into the life sciences, for instance, there is definitely a different language that's spoken and a different vocabulary. And surprisingly, the technology that one finds, at least that I've encountered, is not as advanced in the life science area as it would be for a similar problem not in the life sciences- and there's a good reason for that.

If a technology is going to be adopted for something like human health, it has to be quite robust, so technological advancements aren't as rapidly accelerating in life sciences as if they were commercial products or something like that. That's great for device engineers because we're like, OK, we can go back and look at how things were done. We don't necessarily have to push ourselves in some aspects as hard as we would in others.

But there are two different vocabularies, two whole different dictionaries even, when you're talking to a clinician than if you're talking to someone like an aerospace engineer. That's challenging at first. Because I have very little functional knowledge of anatomy, and many of the devices that we worked on over the years are going to be implantable devices, I learned early on not to worry about things that I don't really need to know, and let the clinician handle that.

If there's going to be a collaboration, we work hard to distill down the critical bits of information necessary for the engineering students to come up with meaningful designs. Essentially the collaborators will create a set of technical specifications of what they want the device to do, what the device is allowed to do and not allowed to do, what it cannot possibly be made of to the best of their knowledge, among other factors.

Then, my students and I will come up with proposed designs based on that and turn the devices back over to the collaborators. Initially, both my students and their students will do some testing. We'll get data that my students can use for their thesis or dissertation and papers, and then we'll turn the devices over to the the clinical researchers, and then they can do their clinical research- if the device works of course- and then they have a way to generate data that they couldn't do if they were going to buy a similar device from a commercial vendor. By doing it locally, we can customize

the device for a specific need as opposed to pulling a more generic device out of the catalog. It's quite exciting. You learn a lot!

Similarly, I had a couple collaborations with physicists, and of course my training is in physics, so I was a bit excited about that at first, but then I was a bit intimidated because I had migrated away from the field and they were asking me to collaborate. They were interested in a material that my group was producing for microdevices and they saw potential applications. One collaboration was about a metamaterial, and metamaterials have interesting optoelectronic properties. This one allowed you to make a focusing lens from a flat sheet. Another one was in the area of defects related to quantum computing. I didn't have to do much of anything other than produce the material, but the material that we had produced had these interesting properties, so I was able to learn about my material in a way that I would never have even thought of if I hadn't had those collaborations because I wasn't focused on those properties at all. I didn't even know they existed. When you're in materials and devices, it can open up doors that you could never anticipate.

Q: Going back to your own research, you are definitely interested in MEMS. Describe more about what MEMS are to the readers.

A: MEMS, short for microelectromechanical systems, has a couple of key components. Micro implies microscale or micron dimensions. Electromechanical indicates that the devices have both electrical functionality and mechanical functionality. A classic device like this would be a micro machine cantilever that could be put into mechanical motion by the application of an electric field. That's just one example. There's plenty of other ones. And then systems implies that the devices themselves don't provide much functionality unless they're connected in some way to a bigger component or a bigger system. For example, maybe the MEMS device functions as a sensor or actuator because it's made on the microscale and often, but not exclusively, made from semiconductor materials so it can be integrated with integrated circuits to create a full system where you have onboard electronics for something like control and then you have the MEMS for sensing and actuation.

Historically speaking, MEMS was born from the semiconductor industry and MEMS were constructed from the classic common semiconductor materials like silicon, silicon dioxide, silicon nitride and the metals that are used in integrated circuits. My speculation is that the main reason that happened is that the semiconductor industry had already figured out the techniques needed for miniaturization, and the MEMS community wanted to leverage that so researchers adopted the materials and the materials fabrication toolset to make the devices. The main difference is that an integrated circuit has no moving parts and some clever scientists and engineers figured out how to do selective etching such that some semiconductor materials, when properly fabricated, can actually have degrees of motional freedom.

Q: Do you mind sharing with us something about the future of MEMS that excites you, such as notable and novel applications?

A: Before I get to the future, let me give you a little evolutionary pathway. Silicon was the dominant material, and, here at Case, there were some visionary faculty who said "MEMS shouldn't be limited to silicon as a material and to applications where silicon is well suited". These researchers, including my mentor Professor Miron Margani- he was the leader and the thought leader on this- looked at areas where MEMS could be applied, but silicon was not well-suited. There are a number of aerospace applications where the environments are too harsh for silicon-based MEMS, but the device technology would be highly enabled. This includes gas turbine engine instrumentation where the temperatures are at 500°C or higher--high-wear, high-radiation, high-corrosion environments where silicon would just break down. Silicon's, for lack of a better word, cousin material, silicon carbide, is well-suited for that. When I came into the MEMS, we put significant effort in developing the materials and fabrication approaches to realize silicon carbide, which we still work on today.

MEMS really took off when groups including Case and other places figured out that the microfabrication techniques used in silicon could be applied to a whole bunch of other different material systems, including polymeric materials. Medical implants based on them were then developed, and then many of the devices used flexible and stretchable polymeric materials rendered on the microscale to make devices using very similar fabrication approaches. Most of those are subtractive in nature. They take positive film and use photolithographic patterning to create structural patterns, which is then followed by etch to render a structural shape into the originally deposited film.

> "Any one person can't be in command of all of the information necessary to be successful—they need to leverage the knowledge that come through these interdisciplinary partnerships."

Then printing techniques began to emerge, in part enabled by MEMS. Some of the most high fidelity printers use MEMS-fabricated printheads to do printing because printing is additive. The MEMS community picked up on that and started to develop approaches for additive manufacturing of MEMS devices through 2D and 3D printing. I've migrated towards that because the printing approaches are attractive as a low cost alternative to fabricate devices, especially from non-silicon materials like polymers and metals. Stretchable and flexible electronics leverage heavily from MEMs tech, and that's what I spend at least half of my time working on these days. The application areas are largely in the biomedical engineering space.

What I just described involves adding materials and processes to the MEMS toolbox, which enables use of many different silicon-based device types with properties that silicon does not have. This broadens the application space. The Internet of Things, for instance, is enabled by sensors and actuator systems that are miniaturized, and now the Internet of Things is much broader than it would be if it was reliant solely on silicon.

The other avenue that I think is equally exciting, both on the engineering and scientific side, is to go down to smaller dimensions than the microscale: the nanoscale. There is an approach to realize the nanoscale, which leverages the microscale through subtractive processing, but with lithographic pattern patterning techniques that are on the nanometer scale. We did some work in silicon carbide NEMS. The offshoot of MEMS, when you go to the nanoscale, is NEMS, which is short for nanoelectromechanical systems. I did some collaborative work with Caltech more than 20 years ago to realize one of the first NEM structures made from silicon carbide, and in the collaboration, fabricated the first-ever mechanical resonator that oscillated with a fundamental frequency of over 1 gigahertz. That had not been realized before. You get to a gigahertz and even higher frequencies by shrinking the dimensions down.

It was a simple beam anchored on both sides that could be excited into resonance, but because two of the dimensions were nanoscale dimensions, the excitation frequency was over a gigahertz. It hadn't been figured out how to do that so successfully in silicon up to that point.

The other offshoot is then to take MEMS technology and head towards the nanoscale. The exciting thing there is that when you go to the nanoscale, you start to get further and further into the domain of science, and to a generation of new knowledge; but coming from an engineering perspective it's science with a pathway, or at least a potential pathway, towards applications because it's enabled by engineering!

Q: Do you say this is a generation of new science because of the quantum effects?

A: You go to the nanoscale to realize quantum effects, but to get to the nanoscale, if you use engineering principles, then potentially, if you identify some quantum effect, you have a pathway to exploit it. Practical exploitation of anything like a quantum effect or a nanoscale effect means we'll have to transition from nano to micro to macro.

We live in the macro world, right? To exploit quantum mechanical behavior while we exist in the macro world requires bridging through the various key dimensional scales. MEMS technology microfabrication provides that pathway. So it's not just knowledge for knowledge's sake without a way by which we could envision exploiting it. The systems necessary to gain that knowledge are engineered systems that are already providing the bridge from the macro world to the nano world.

Q: Do you feel like these advances in technology are requiring more emphasis on science education of engineers at the level you would expect from the natural science community?.

A: I can say with certainty that the natural science component to an engineer's education is critically important. The questions that come up are "how much?" And "at what cost?" Ultimately, there's a limit to how much we can expect the student to learn in a reasonable period of time, and if we pack more of the natural science topics in the time to achieve a degree, what do you lose?

I have thought about this a lot, and I'm pretty happy with where we're at for a couple of reasons. For one, I think an interesting research area, be it in science or engineering, is one that happens at the intersection of disciplines and requires the practitioner to be collaborative. Why? Because any one person can't be in command of all of the information necessary to be successful- they need to leverage the partnerships and the knowledge that comes through these interdisciplinary partnerships.

So then the question is: what makes for a good collaborator? A good collaborator, in my opinion, is one that has a strong drive, great communication skills, and knows how to work effectively in a team, especially within a team of varying personalities. That needs to be learned, and it can be developed. Some of those skills are developed by taking courses that have nothing to do with the natural sciences. I think that's where the liberal arts component of an engineer's or a scientist's education becomes important.

I came about it through a really weird way because, as I told you, I have a BA in economics, which is, at best, a soft science like social sciences, where collaboration and interactions and stuff are definitely part of the training. And then I also have this really hard science stem education. Because of that, I do see the value in the training I received from the former. My research success would not be where it is today if I didn't know how to collaborate. I actually credit my BA in the advancement of my career as much as my BS, MS, and PhD because without those collaborators, I wouldn't be where I'm at today for sure. I'd probably have a very narrow research pathway with limited productivity. My research success is amplified by my ability to collaborate. I'm a proponent of balance in education. There are a lot more of us STEM people out there today than there were 50 years ago, but I think that there will be no loss of knowledge. They'll just be working more on team science than we would have 30 years ago.

Q: Speaking of resources, you're the Dean of Research for Case School of Engineering, so what are some of the research directions here at Case School Engineering that you're most excited about for the future?

A: Well, first I should state that the School of Engineering and the Dean's office does not decide the research agenda. Our job in the Dean's office is to facilitate world class research that's performed by our faculty and teams of faculty, both within the school and with our faculty collaborators in other schools and colleges outside. We are basically trying to make our faculty as productive as they can be. The research topic areas that are prominent within the school are those that have been fostered and developed well.

The faculty incubates and fosters those good ideas so they can be successful. We rely 100% on our faculty to come up with the great ideas, identify the vexing problems, and come up with the teams to solve the problems. I'm really excited about the Human Fusions Institute because it leverages three or four areas of research strength within the school- our long history of neuroengineering combined with our fruitful history in robotics and electronics.

> "There's not an engineering discipline that does not use electronics, electrical systems, or measurement systems that are based on electronics, in one way, shape, or form."

It really is a classic example of multidisciplinary research. The Human Fusions Institute recognizes that there's a bioethics component to what they do, because it's that it's really at the edge of where humans and technology are interfacing, so they've incorporated bioethicists in the project. It's a comprehensive approach to that topic area of human machine interfacing. I think that's exciting. I think our excitement is justified by the recent press coverage. Dustin Tyler and Bolu Ajiboye were on 60 minutes, as well as a number of Case students, and other researchers that didn't get called out by name.

We have strong research activities in energy, and in particular, energy storage. Within energy storage, we have a focus on those that are enabled by electrochemistry. I'm really excited about those. I'm excited about the work we're doing in the application of data science techniques as it relates to materials and materials degradation. I think we're second to none in that area. In device technologies as it relates to human health, our point of care technology research that is coming out of mechanical, aerospace, electrical, computer, and systems engineering is really exciting. What we've done in the school, through faculty input, is identified a handful

of thrust areas where we know we already have world class research and we are going to push those topics and research areas into preeminence so that when people think of Case Western Reserve University, they're going to think of human fusion and the other big topics mentioned.

Q: I feel like this interview would be missing if we did not talk about your teaching. You've taught many core engineering classes at Case, including Introduction to Circuits and Instrumentation (ENGR 210), Semiconductor Electronic Devices (ECSE 321), and more. Can you share with us some aspects of your teaching philosophy and what shaped it?

A: As you know, I don't have any formal engineering training. My degrees are in economics and physics, so I have to approach the classes I teach with that in mind. My colleagues were wise enough to give me an intro circuits class. There are some circuit classes that are beyond my knowledge. Eventually I could teach them if I had enough time to prepare, but there are only so many hours in the day. I had an instrumentation class when I was an undergrad physics major, and it was different compared to the circuits class that we have to teach as part of the core. Instrumentation class was to prepare physics majors for experimental physics where instrumentation was key. So it was less about circuit solving techniques and it really didn't align itself to developing circuit designers, because that's not what physicists tend to do.

We can design some circuits, but we're designing circuits to make a measurement or do some experiment. Efficiency is not necessarily the driving thing. We're not going to be designing circuits as a primary component of what we do. When I picked up the circuits class, what I recognized is that most students there probably aren't eager to take the class. If they had the choice, they probably wouldn't. For those students, my primary objective, in addition to exposing them to the necessary information to understand circuits, is to sharpen their problem solving skills. That is the thing that has a lasting legacy.

For some, circuits is just another chance to hone their problem solving skills. For those who are interested or will be working in areas that require circuit solving techniques, I want them to have a full toolbox so if they get into an advanced circuit class and the professor says, "reduce this circuit to a Thevenin equivalent," without hesitation, they could go do it. They might have to look up to refresh their memory on how to do it, but that refreshment would not take that long.

Then there are some that I want to inspire. Maybe they haven't made their decision yet and I want to inspire them to consider electrical engineering as a major, but I don't go into it thinking that I should convert everybody who is taking the class.

I do want to demystify electrical engineering somewhat. I tell the students that they need to recognize that engineering does not happen in the modern world without electronics. There's not an engineering discipline that does not use electronics, electrical systems, or measurement systems that are based on electronics, in one way, shape , or form. It's important that they understand at least a little bit about how those things work.

> "Always test that the vision you have for the future is your vision, and not a vision imparted on you by somebody else, simply because you were good at this or good at that."

My teaching is now limited to the circuits and the semiconductor class because I'm in the Dean's office, but I used to teach a class in nanotech, a class in microfabrication, and a couple of other classes. I now teach the required semiconductor device physics class in the electrical engineering curriculum. Similar to ENGR 210, I think it's important for electrical engineering students, and those who are interested in electronics, to have a class like this. The core of modern electronics is the silicon-based transistor. You could be a successful engineer, and even a successful electronics engineer, without knowing how the transistor works on the inside, but to appreciate where electronics is going, and it's getting there rapidly by the advent of new materials and nanotech, and maybe anticipate where you might want to be in this ever evolving field, knowing the fundamental device physics behind the transistor is key.
When they're out there five years from now, and somebody's saying, "here's a new transistor design, and it's enabling this that or the other thing," I want students in the class

> "Technologies may have contributed to the problems we have, and since we're not going to give up on technology, we have got to seek technology-based solutions."

to understand that at least a high level how that transistor works by leveraging the knowledge about the classic transistor so they can engage in meaningful discussion with somebody who might be talking about this. And who knows? That might lead to a job that they wouldn't otherwise have if they couldn't have engaged with that person.

We take a scientific and engineering approach. I'm not teaching advanced math at this stage. I'm challenging students to assimilate quite a bit of information and apply that information to problems associated with semiconductors. It is teaching new vocabulary and new language, and presenting problems where students have to decode the information given. The math that is necessary to solve the problems that we'll address in class is pretty straightforward math, but that doesn't mean that the class isn't challenging. Math in the context of information can often be very challenging. So I enjoy that class.

Q: Considering you have explored quite a broad range of interests through your career, what advice do you have to help younger people explore their interests and navigate them meaningfully?

A: I came to research by a really non-standard path. First, I was going to become a lawyer. Then I worked in a food science lab. Then I worked in a meteorology research lab at Ohio State. I worked at Nestle. And then I ended up in physics. When I reflect back on why I started my undergrad career thinking I should be a lawyer, it's partly because I was told that I should be an attorney and I had a firm that was in my family. It seemed to be my destiny. If I had not explored other options and opened my mind to whatever else could be out there, I'd be an attorney. Maybe I would be a successful one and maybe I would be happy, but somehow, I explored other options.

The job that I got in the lab for meteorology was simply because I was looking for a paid position while I was in undergrad that was something other than working security in the dorms, which I was doing at the time. I needed something different, and I said, "I want to work in a lab." In physics, all the lab jobs were taken, but I needed something in a lab, because I didn't want to work in food science or security. I happened to find a posting on a sign board out on the Oval for a researcher looking for a research assistant at minimum wage. I was like, OK, let's go check it out. Meteorology. Let's see what it is." I figured it would be better than sitting by the front door of my dorm checking people in.

That was a life changing experience. I published 2 papers from that experience. And I said, "what skills do I need? I know nothing about meteorology other than watching the weather report on the nightly news." The guy asked me my major, and I said I was a physics major. He goes, "that's good. Nobody comes in here with the skills we need, but we need you to be STEM-oriented." I asked what they were going to have me do. He says, "we have these photographs that the Navy has taken over the Antarctic Plateau, and in these photographs of snow fields, there's information about wind direction. We're basing our work on a 1918 paper published by some Russian scientists that did work in Siberia on weather patterns. We're going to figure out if we can use that same method on these photographs. For the task, you just need to be halfway decent in geometry and you need to be persistent," because there were around 5000 of these photographs.

From these photographs, we constructed the most detailed map of that region of Antarctica that had ever been made at the time. This was pre-satellite imagery. We came up with the data set that was used for a simple model of wind patterns over the Antarctic, and its influence on sea water temperature in the Southern Ocean, which feeds the ocean currents in the mid latitudes that are associated with El Niño and La Niña events.

I would never have thought in a million years that's what I would do. I stayed at that job for 2 1/2 years. In the summers, I worked at a research facility in my hometown. It was again a summer job where I had started cutting the grass, and then they told me they needed some summer help in a lab. They asked me if I wanted to move into the protein synthesis lab, and I agreed.

Through those experiences, I began to see that a career in research seemed pretty interesting. So I guess the advice is to walk around with your eyes wide open, and don't be

afraid to explore. Always test that the vision you have for the future is your vision and not a vision imparted on you by somebody else simply because you were good at this or good at that. And usually if you're good and you like to interact with people, good things will happen. I mean, I didn't even come into MEMS with that focus. After my PhD I was going to do a postdoc, and I was actually exploring a postdoc at a university in Australia at the time, but it wasn't clear whether they were going to have funding for it. It would have been in diamond surface related research. I had another lead as a postdoc at NASA Glenn, but none of them were solid, and then this one in MEMS came up. They were looking to hire somebody immediately, so Idid a little bit of research on what MEMS was and I thought "that sounds pretty cool." I'd better go with what I have at hand because at the end of the day I need a job. So I took the one that was readily available and I've never looked back.

Q: What advice do you have for your future engineers and researchers?

A: I will say that I don't think there's ever been a better time to be a researcher or a research engineer, because there are some significant challenges that humanity faces. Problems that we need to resolve, and then particularly for engineers, technologies that are necessary to solve those problems. Technologies may have contributed to the problems we have, and since we're not going to give up on technology, we have got to seek technology-based solutions. If you're passionate about those things, then get started. I will say this for Case: I think the education that you receive at Case will prepare you very well for a future in whatever you choose to do. It might not seem like that at the time because there are the challenges of education, but I have run into many graduates who said their Case education prepared them so well that they are on par, or even better than, their colleagues that came from higher-ranked schools.

So as for advice- you're not going to learn about the great opportunities unless you extend yourself. Talk to people, engage with your professors, engage with other people who are doing interesting things. Oftentimes when you can get some professor to free up some time, they'll be more than happy to talk to you about your research. So knock on doors, I guess.

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Credit: Grace Huang, Kit Shiells

Review of the Safety and Efficacy of Trauma-Focused Treatment Among Patients With Psychosis

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Abstract

Among people who experience psychosis, many have comorbid post traumatic stress disorder (PTSD) that is frequently undiagnosed and untreated. Symptoms have long-term implications, such as hallucinations, post-traumatic intrusions, and an increased risk of physical health conditions, like heart disease and respiratory issues. Many clinicians believe that diagnosing and treating PTSD in this population will be dangerous, so these patients are often excluded from trauma-focused treatment based on their psychosis symptoms. This paper will review current data regarding the rates of undiagnosed PTSD among this population as well as the safety and efficacy of treatment options. PubMed was used to identify peer-reviewed, academic journal articles pertaining to, "PTSD," "psychosis," "trauma-focused treatment," "content of first episode psychosis," and "schizophrenia." Eleven empirical studies were identified and included in this review. The results showed rates of PTSD among psychosis patients are much higher than currently identified, with one study finding that 16% of participants suffered from comorbid PTSD with only 0.5% of the population having been diagnosed previously. Data also showed that treatment for PTSD was safe and decreased both PTSD and psychosis symptoms in this population. These results strongly indicate that additional studies should be conducted in order to determine which trauma-focused treatments are the most safe and effective for this population. Clinicians working with psychosis patients should be informed of the results of these studies in order to encourage them to diagnose and treat the PTSD of their patients along with their psychosis.

Review of the Efficacy and Safety of Trauma-Focused Treatment Among Patients With Psychosis

Psychotic disorders are a debilitating group of mental illnesses associated with stigma in many cultures today (Eliasson et. al., 2021). The prevalence of these disorders is somewhat difficult to determine, but it is estimated that approximately 3% of the global population has experienced a psychotic disorder at some time in their life (Perälä et. al., 2007). The exact mechanisms of these disorders is unknown, but some psychologists believe that one factor in the development of a psychotic disorder could be the aftereffects of trauma (Croft et. al., 2019). Preliminary studies have shown that the incidence of experiencing a traumatic event is higher among psychosis patients than the general population (de Bont et al., 2015). However, patients diagnosed with a psychotic disorder are often excluded from trauma-related therapy due to concern over how well they will tolerate the difficult treatment process (de Bont et al., 2016). This has led to a large population of psychosis patients suffering from undiagnosed PTSD, further decreasing their quality of life (Buckley et. al., 2009).

Although psychotic disorders share many symptoms, seven separate diagnoses fall into this category (American Psychiatric Association, 2013). Schizophrenia is the most well-known, with symptoms including auditory and visual hallucinations, disorganized speech and behavior, catatonia, and negative symptoms (such as decreased emotional expression). If symptoms last longer than six months, the disorder is classified as schizophrenia, but if symptoms are present for less than six months, it is considered

BIOGRAPHY

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schizophreniform disorder. Brief psychotic disorder is very similar, but symptoms only last between one day and one month. Schizoaffective disorder is also similar to schizophrenia, but patients experience symptoms of major mood disorder alongside those of psychosis. Schizotypal personality disorder is not always considered a psychotic disorder, but symptoms are somewhat similar and include cognitive distortions and eccentric behavior. Delusional disorder is categorized by experiencing delusional beliefs, which can include the idea that one is being conspired against or has a great talent that others fail to recognize. Catatonia is defined as decreased motor activity, decreased engagement, or excessive movement. It is difficult to classify because it can present as extreme agitation or flat affect. These conditions are much more complex than these descriptions allow, but they are generally categorized by the presence of delusions, disorganized thinking and motor behavior, negative symptoms, and hallucinations. These symptoms can be extremely disruptive of everyday life and often lead to suicidal ideation. In patients with schizophrenia, approximately 5% die by suicide, and close to 20% attempt suicide. The stigma surrounding these symptoms only leads to more distress for patients (Eliasson et. al., 2021). Furthermore, patients may have a difficult time discussing their symptoms with loved ones because they fear judgment. Thus, if therapists do not feel comfortable talking about trauma-related symptoms, patients may not have anyone in their life to talk with whom to talk about their hardships.

PTSD is distressing on its own, with symptoms like hypervigilance, the inability to experience positive emotions, avoidance of thoughts or external reminders related to the traumatic event, involuntary memories of the event, and dreams related to the event (American Psychiatric Association, 2013). Symptoms may also include depersonalization, which is characterized by feeling detached from oneself, or derealization, which is classified as feeling as though reality is not real. These symptoms are reminiscent of some aspects of psychotic disorders, like hallucinations and delusions, but are related to a specific event. The similarity between some symptoms of PTSD and psychosis supports the hypothesis that psychosis may sometimes stem from a traumatic event. PTSD is not rare, with an estimated 8.7% of Americans experiencing PTSD at some time during their lives. PTSD has been shown to be correlated with physical disability, as well as difficulty functioning socially and occupationally, and is associated with suicidal ideation. Studies have shown that people with PTSD have a high mortality rate and an increased risk for health conditions including cardiovascular disease, respiratory illness, and neurological diseases (Calhoun, 2006).

Both psychotic disorders and PTSD are associated with suicidal ideation, stigma, and decreased quality of life (American Psychiatric Association, 2013). Patients who suffer from both mental illnesses simultaneously experience the stigma and other associated risks for both disorders, potentially leading to worse outcomes. Increasing knowledge regarding the safety and efficacy of treating patients who are suffering from both disorders could greatly improve their quality of life and decrease mortality rates among people with these disorders each year. The purpose of this paper is to assess the safety and efficacy of the diagnosis of PTSD among psychosis patients and current treatment options for trauma-focused therapy for this population. This paper hopes to gain a better understanding and provide insight into how to best provide care for these patients.

> "The strongest correlations were found between psychosis symptoms and sexual assault, bullying, and emotional neglect"

Literature Review

Diagnosis of PTSD

In order to improve treatment options for patients with comorbid psychosis and PTSD, it is important to first have a reliable method of diagnosis. In an attempt to determine if this is feasible, de Bont et al. (2015) created the Trauma Screening Questionnaire and administered it to 2,608 patients in long-term care facilities in the Netherlands. Participants were included in the study if they were diagnosed with a psychotic disorder or had psychotic symptoms with an ongoing mood disorder. They included adults aged 18 to 65 and excluded patients with a comorbid intellectual disability. The survey had been previously tested on non-psychosis patients and was shown to be effective in diagnosing PTSD. The survey included questions that screened for different types of trauma, including: sexual assault, severe neglect, physical abuse, emotional abuse, accidents, and natural disasters. In order to ensure safety, they administered the survey under the direction of a mental

Study	Meets Criteria for Diagnosis of Psychotic Disorder	Experienced at Least One Traumatic Event	Meets Criteria For Diagnosis of PTSD	Previously Diagnosed With PTSD
de Bont et al., 2015	100	100	16	0.5
Kilcommons and Morrison, 2005	100	94	53.1	5
Croft et al., 2018	100	83.8	n/a	n/a
Peach et al., 2021	100	67	27	n/a

Table 1: Percentage of Psychosis Patients Who Have Experienced Traumatic Events

Notes. Percentages of participants who meet criteria for diagnosis of PTSD and those who were previously diagnosed with PTSD were calculated from the percentage of those who had experienced at least 1 traumatic event.

health professional. Once the results were calculated, a second survey was administered to patients whose scores indicated a PTSD diagnosis. In order to ensure the validity of their results, the second survey was also completed by a randomly selected group of participants with few PTSD symptoms.

Their survey showed that 16% of the participants had diagnosable PTSD, but only 0.5% had been diagnosed previously. This result, shown in Table 1, signifies that 96.6% of the participants in this study who suffered from comorbid psychosis and PTSD had not been previously diagnosed with PTSD. These results are even more striking when compared to the rate of PTSD among the general population of the Netherlands, which is only 3.3%. The survey was shown to provide a correct positive result 44.5% of the time and correct negative result in 93.6% of the cases, which was found to be statistically significant.

After the results had been distributed, the participants were asked to evaluate their experience taking the survey in order to ensure that the diagnostic process was safe for this population. Zero participants expressed any negative impact of the survey on their mental health and most stated that they were relieved to be offered help with their PTSD symptoms. This is an extremely important result because it shows a potentially reliable way to diagnose psychosis patients with PTSD without causing distress. However, this study excluded patients who were being treated in a closed ward, meaning they potentially excluded patients with severe psychosis symptoms. It is also difficult to know if every participant with PTSD was correctly diagnosed because the sample size was too large to conduct in-depth interviews. However, these results are consistent with the established connection between psychosis and PTSD.

Kilcommons and Morrison (2005) also showed evidence for the connection between psychosis and PTSD by assessing 32 patients aged 18 to 60 with schizophrenia spectrum disorders being treated by psychiatric services in England. They used interview and self-report data to screen for the same types of trauma as de Bont et al. (2015) and included assessments for trauma exposure, psychosis symptoms, post-traumatic cognitions, and dissociative experiences. They found that 94% of the participants had experienced at least one traumatic event and 53.1% were diagnosed with PTSD, while only 5% of those had been previously diagnosed, as shown in Table 1. These findings are consistent with de Bont et al. (2015) and highlight how widespread the underdiagnosis of PTSD is in this population.

They also found that the severity of positive psychosis and PTSD symptoms were related to the severity of the traumatic experience. The data showed experiencing sexual assault was correlated with the highest rates of hallucinations, and higher scores on the dissociative experiences survey, specifically depersonalization, were significantly related to hallucinations. Patients may begin to experience paranoia and delusions following their trauma, which may either create or exacerbate underlying psychosis symptoms in

some people. This correlation highlights the importance of diagnosing this population with PTSD because, if this hypothesis proves correct in even some patients, treating their PTSD could potentially decrease their psychosis symptoms as well. These results are not generalizable because the participants were a small convenience sample and may not have spent enough time with a clinician to establish rapport. However, the results do demonstrate a potential relationship and therefore highlight the importance of developing a better understanding of this topic.

Another study was conducted in 2018 that attempted to provide more insight into the connection between psychosis and trauma. Croft et al. (2018) gathered longitudinal data from 4,433 participants starting before their birth and continuing until they were 18 years old. Data came from a larger study in the United Kingdom, but Croft et al. (2018) looked specifically at the data regarding psychosis symptoms and traumatic experiences. They controlled for family history of mental illness, Intelligence Quotient (IQ), and temperament as a child, among other potential confounding variables. Traumatic experiences were assessed using self-report measures from both the child and parent. They validated the results by collecting data again when the children were 22 years old.

> "Before beginning trauma-focused treatment for a patient with a psychotic disorder, the clinician should discuss the risks of the treatment and they should work together to determine if it is a safe option."

The results showed a strong correlation between traumatic experiences and psychosis symptoms, with participants who had experienced three or more types of trauma having 4.7 times the risk of experiencing psychotic symptoms when compared to participants who had never experienced a traumatic event. The strongest correlations were found between psychosis symptoms and sexual assault, bullying, and emotional neglect. Participants who experienced only one type of trauma were shown to be at an increased risk for psychosis symptoms as well. Physical abuse survivors had a 2.43 times greater risk of experiencing psychosis when compared to those with no traumatic experiences, emotional abuse survivors had 2.23 times the risk, sexual assault survivors had 3 times the risk, and bullying was correlated with 2.1 times the risk of experiencing psychosis symptoms. This highlights how important it may be to treat people for childhood traumatic events when the event occurs because it could potentially stop psychosis symptoms before they surface. More research is needed to determine if the correlation could be causative, but this study provides strong support of the hypothesis. Of the participants who experienced psychosis symptoms, 83.8% had experienced trauma, while only 62.2% of participants with no psychosis symptoms had experienced trauma, as shown in Table 1. This provides further support for a causal relationship between traumatic experiences and the development of psychosis. While more research is needed to confirm these findings, especially since more participants with childhood trauma dropped out of the study than those without, these results provide further evidence of a connection between traumatic experiences and psychosis symptoms.

Peach et al. (2021) conducted a study that relied more heavily on interview data than the previous studies. They recruited 66 participants who were experiencing first episode psychosis from an early intervention center in Australia. They conducted interviews to assess psychosis symptom severity, childhood traumatic experiences, PTSD symptoms, and demographic information, and recorded the content of five hallucinations and five post-traumatic intrusions for each participant. They found that of the 67% of participants who experienced childhood trauma, 82% also experienced hallucinations, and 55% also experienced post-traumatic intrusions. Of the 55% of participants with childhood trauma and post-traumatic intrusions, 92% also experienced hallucinations. The high rates of hallucinations in participants with a history of childhood traumatic events provides support for the relationship between PTSD and psychosis.

Researchers also analyzed the content of hallucinations from the population that experienced trauma and hallucinations. They found that 78% of participants had experienced at least one hallucination that was similar to their traumatic event. Most participants in this category also experienced at least one hallucination that was deemed unrelated to themes present in their traumatic event. A large number of participants experienced hallucinations similar to their traumatic experiences, which could potentially be treated through trauma-focused treatment. As shown in Table 1, results showed that 27% of participants suffered from

comorbid PTSD, which was found to be higher than the rate of PTSD among the general population of Australia. More research needs to be conducted in this area in order to determine if there is a true connection between traumatic experiences and hallucination content because 81% of the hallucinations recorded did not have similar content or themes to traumatic experiences of the participant. If there is an association between themes of psychosis symptoms and traumatic events, it could provide insight into how to best treat PTSD among psychosis patients.

The first part of this study was conducted a few years earlier (Croft et al., 2018) and Peach et al. (2021) found similar results using self-report measures. They found post-traumatic avoidance to be correlated with the severity of hallucinations and that post-traumatic intrusions were correlated with the severity of delusions. In other words, patients who experienced certain types of trauma-related symptoms experienced more severe psychosis symptoms. These results, while not necessarily generalizable to older populations, show there is a potential connection between traumatic experiences early in life and first-episode psychosis that could be helped with early intervention.

> "After the 8 weeks of therapy concluded, patients who received trauma-focused treatment showed a decrease in both PTSD and some psychosis symptoms, including paranoid thoughts."

Quality of Life in Psychosis Patients with PTSD

Many studies focus on underlying PTSD among psychosis patients, but Kilcommons et al. (2008) assessed underlying psychosis symptoms among a group of survivors of sexual assault. Participants were recruited from local support centers and colleges, and were excluded from participating if they had a history of psychosis symptoms prior to the assaults. Researchers included a convenience control group that was recruited from local colleges and ensured that the age range was similar to the group of sexual assault survivors. Using a combination of self-report and interview measures, they assessed auditory and visual hallucinations, delusions, PTSD symptoms, and dissociative experiences. Results showed 100% of the survivors had experienced delusional ideation to some degree, 90% selected "yes" for at least one of the questions related to auditory hallucinations, 92.5% selected "yes" for at least one question related to visual hallucinations, and 65.8% reached the threshold for a diagnosis of PTSD. Some of the assaults took place many years prior, so not all participants were still experiencing the symptoms required to be diagnosed with PTSD at this time. The results of this study may be more extreme than studies that assess different forms of trauma because most studies (Croft et al., 2018) have found that sexual assault is typically more strongly related to psychotic symptoms than other types of trauma. The population mostly consisted of a small group of white women, so more research would need to be conducted in this area in order to provide generalizable results. However, this data is consistent with the correlation previously demonstrated between psychosis symptoms and experiencing traumatic events.

It is important to estimate the impact that symptoms of comorbid PTSD and psychosis have on patients' lives in order to determine if treatment would be worth the potential risks to this population. Calhoun et al. (2006) assessed these factors among 165 veterans with a primary diagnosis of schizophrenia or schizoaffective disorder who were admitted to the Veterans Administration Hospital between 1998 and 2000. Participants took a survey assessing their physical and mental health in order to estimate their quality of life. In addition, their medical history was obtained to determine if there was a quantitative difference between the number of visits to the hospital in patients who suffer from schizophrenia and those who also have comorbid PTSD. Among the 41% of participants who had comorbid PTSD, scores on the quality of life surveys were significantly lower for mental health and slightly lower for physical health. Participants with comorbid PTSD also visited the hospital more than patients without PTSD. These results demonstrated the need for research to assess treatments for the comorbidity of PTSD and schizophrenia because their quality of life is worse than those with only schizophrenia. This study may not be generalizable because it only included male veterans and did not control for how long they had been out of combat.

Treatment of PTSD for Psychosis Patients

Therapists have expressed concern over trauma-focused treatment for psychosis patients because they are worried

> "Increasing knowledge regarding the safety and efficacy of treating patients who are suffering from both disorders could greatly improve their quality of life and decrease mortality rates among people with these disorders each year."

that talking about trauma with these patients would be too risky for their mental health. However, van den Berg et al. (2016) provided support that this reaction does not typically occur. They gathered a group of 16 therapists from the Netherlands specializing in psychosis with no experience in trauma-related therapy and trained them in cognitive behavioral therapy. They assessed the therapists' opinions about trauma-focused treatment for psychosis patients before and after treatment. Many of the therapists were concerned that treating this population for PTSD would have a high burden of care. However, when researchers followed up with participating therapists two years after the study had concluded, every therapist who was still working with psychosis patients was still using trauma-focused treatment. This study had a small sample size, and the therapists had strict protocols to follow, so it might not be generalizable to every clinician, but the results provide support that therapists should not assume treating this population will always cause harm to either party. The aggregate symptoms of the 79 patients improved over the course of treatment, regardless of their therapist's original feelings toward using trauma-focused treatment for this patient population. Even if clinicians are nervous to begin trauma-focused treatment among this population, preliminary results provide support that it is safe and effective.

Another study investigated the response of psychosis patients to trauma-focused therapy (Tong et al., 2017). They recruited participants from a treatment center in Australia with current symptoms related to a traumatic event and either a psychotic disorder or a mood disorder with psychotic symptoms. They taught participants about the physical symptoms of both PTSD and psychotic disorders in order to help them understand their trauma and how it impacts their psychosis symptoms. Patients also documented the timeline of their trauma, which has been shown to provide therapeutic results similar to exposure therapy. The therapists taught patients how to determine if they were really in danger and how to calm down if the panic stems from trauma-related symptoms rather than a true threat to safety. Throughout this process, participants were asked to document their thoughts about the treatment and their level of distress. While some participants felt an increase in overall symptoms at the beginning of therapy, 86% showed clinically significant improvement in both psychotic and PTSD symptoms by the end of the study. This study showed that trauma-focused treatment should be conducted in a controlled environment where the patients can receive consistent help because 25% of the patients experienced an increase in suicidal ideation at the beginning of the treatment. However, every participant in the study said the treatment was worth the discomfort and helped them overall. This result provides evidence that people with psychosis may be able to withstand the difficulties of trauma-focused treatment. Further research should be conducted in order to determine which types of trauma-focused treatment have the lowest risk of increased suicidality.

There is preliminary research detailing the results of eye movement desensitization and reprocessing (EMDR) and prolonged exposure therapy for psychosis patients, including a study conducted by de Bont et al. (2016). They gathered 155 patients with a lifetime psychotic disorder and comorbid PTSD from Dutch outpatient services. Patients were excluded if they changed medication during the experimental time-frame. Participants continued their psychosis-related therapy and either received EMDR, prolonged exposure therapy, or no additional therapy. The control group waited until the trial was finished, and they received the treatment of their choice in order to maintain an ethical trial. Therapy included weekly 90-minute sessions for 8 weeks. They measured psychosis symptoms, depression, and social skills through self-report surveys, and therapy sessions were supervised in order to ensure protocol was followed.

After the 8 weeks of therapy concluded, patients who received trauma-focused treatment showed a decrease in both PTSD and some psychosis symptoms, including paranoid thoughts. A few patients went into remission from their psychotic disorder, but most saw no changes in frequency of auditory or visual hallucinations or social skills due to the treatment. Prolonged exposure therapy showed greater decreases in symptoms than EMDR treatment.

Six months after therapy ended, de Bont et al. followed up with the participants, in a study published in 2018. Participants who received EMDR had a greater reduction

in symptoms than they did directly following the 8 week therapy period, indicating that they continued improving after treatment ended. Patients who received prolonged exposure showed the same symptom severity as they did directly following treatment, suggesting their improvements were well maintained after treatment terminated. They reassessed the effect after one year and found the same results. Their study showed that, although trauma-focused treatment didn't decrease depressive symptoms or visual or auditory hallucinations, it did reduce paranoid and delusional symptoms and PTSD symptoms. This prolonged reduction of symptoms provides strong support that there may be a treatment for PTSD among people with psychotic disorders that could improve their quality of life.

Discussion

The results from the studies above show that there are a significant number of people who meet the criteria of diagnosis for a psychotic disorder and PTSD who are unable to receive effective care for their mental illnesses. Because clinicians believe that these patients are unable to manage even talking about their traumatic events (van den Berg, 2016) and there are many people suffering with no one to talk to, the burden of care is placed on the patient because their therapist will often not attempt to assess their trauma history. Due to the high rate of comorbidity found in these studies, trauma-focused informational resources should be made available to every person with a psychotic disorder. Screening protocols should be implemented in order to deliver informed treatment that targets all of the symptoms that are decreasing their quality of life. More research is necessary to determine which screening tools are best at assessing trauma-related symptoms in this population. The creation of a new screening tool may be necessary in order to effectively separate psychosis symptoms from PTSD symptoms while causing as little harm as possible because discussing trauma history may cause psychotic symptoms to increase (Tong et al., 2017). Therapeutic rapport may need to be established before these screening tools can be used in patients who experience paranoid delusions.

> "Thus, if therapists do not feel comfortable talking about trauma-related symptoms, patients may not have anyone in their life to talk with whom to talk about their hardships."

Overall, the studies found that patients with psychosis were relieved to be able to discuss their trauma with a therapist and said the treatment was worth any discomfort they experienced (Tong et al., 2017). However, it is still important to note the increase in psychosis symptoms and suicidal ideation that occurred in some patients. Before beginning trauma-focused treatment for a patient with a psychotic disorder, the clinician should discuss the risks of the treatment and they should work together to determine if it is a safe option. They should also create a plan in the event their symptoms increase, including coping mechanisms geared toward each patient's specific symptoms and a support system they can turn to. The patient should spend time practicing the coping mechanisms before the onset of treatment and members of the support system should be informed of the possibility that they may be asked to help. The support system may include a clinician, family, or friends who the patient would feel comfortable going to for reality testing or to discuss difficult thoughts they may be having. They should discuss the possibility of suicidal ideation during the course of treatment and have specific steps in place if these thoughts occur.

Another main concern surrounding trauma-focused treatment for patients with psychotic disorders is the impact it will have on the mental health of treating clinicians. The studies in this review found that these concerns were eased upon delivering the treatment. This may not be true for every clinician, for example those with a history of trauma in their lives may have difficulty delivering trauma-focused treatment, but they should still be aware of the potential benefits of the treatment for their patients. Clinicians can then work together with their patients to make informed decisions about the best method of treatment.

There is little research about which trauma-focused treatments are most safe and effective among this population, so more studies should be conducted in order to determine which treatments should be utilized. Educating patients about the symptoms of PTSD and psychosis may be a safer alternative for patients with a history of severe suicidal ideation. Trauma-focused treatment may not be effective alone because delusions and hallucinations do not always stem from trauma (Peach et al., 2021), but patients should not be excluded from education or treatment due to their psychotic disorder diagnosis.

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Credit: Catherine Feng

U.S. Public Equity ESG Fund Composite and Parnassus Core Equity Fund: Performance and Factor Attribution

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Abstract

This is the first paper to examine all U.S. public equity Environmental, Social, and Governance (ESG) funds offered by the Forum for Sustainable and Responsible Investment's (SIF) institutional member firms from 2005 to 2020. For ease of communication, this will be called the ESG Composite. With a Net Asset Value (NAV) over $150 billion, these funds comprise nearly half of the U.S. public equity ESG investment landscape. The article finds that the ESG Composite maintains performance with the Standard and Poor's (S&P) 500 total return index on an overall returns basis with lower volatility, indicating greater risk-adjusted returns. Factor analysis reveals that the ESG Composite returns are primarily driven by underleveraged exposure to market returns as well as prevalence of mid-to-large cap and high beta stocks. When isolating the largest fund in the ESG Composite — the Parnassus Core Equity Fund (PRBLX) portfolio — this study finds significant outperformance over the S&P 500 on an overall returns basis. Factor analysis reveals greater emphasis on underleverage to the market and greater preference for large cap, high beta stocks. When compared to the global mutual fund universe, the ESG Composite outperforms in annualized returns and Sharpe ratios, whereas the PRBLX portfolio outperforms in annualized returns, annualized Sharpe ratios, annualized alphas, and annualized information ratios. Conclusions drawn from this study will (1) supplement the discussion on ESG usefulness and (2) present actionable investment insights.

Introduction

ESG is a broad term that refers to the consideration of environmental, social, and governance standards into investors' decisions for portfolio selections. Generally, ESG companies seek to generate positive societal byproducts as assessed by nonfinancial data such as carbon emissions, employee satisfaction, and board structure (Armstrong, 2020).

In the past several years, ESG investing in the U.S. public equity market increased exponentially, surpassing $380 billion in net assets in 2021 (Lev, 2021). Such rapid popularity was accompanied by heavy controversy and ESG bans across the United States. Florida Governor Ron DeSantis passed anti-ESG legislation in July 2022 that prohibited "State Board of Administration (SBA) fund managers from

BIOGRAPHY

Karthik Nemani is an ambitious and environmentally-conscious sophomore double majoring in Business and Statistics at the Kenan-Flagler Business School of UNC Chapel Hill. Fueled by his passion for environmental sustainability, Karthik combines his interests by observing environmental trends from a financial and economic viewpoint using quantitative statistical tools such as R. Outside of academics, Karthik is an avid outdoors enthusiast who enjoys playing tennis and expressing his artistic side through the violin. Furthermore, he actively contributes to his campus community as the assistant director on the executive committee of the Impact Investing Fund, a student-led organization that manages over $15,000 by investing in ESG-rated companies and strategies, helping to foster a sustainable future through responsible investing.

My name is Barrett Buhler and I am a rising senior studying statistics at UNC Chapel Hill.

considering ESG factors when investing the state's money" (Spectrum News Staff, 2022). In August, Texas Republican Comptroller Glenn Hegar released a list of 10 companies and 348 ESG investment funds — including BlackRock, Credit Suisse, and UBS — that were barred from doing business with the state. A year prior, Texas enacted legislation prohibiting most state agencies and local governments from contracting with such firms (Freedman, 2022).

The primary reason for such bans is the belief that the costs to financial returns outweigh the societal benefits of ESG investing. Florida anti-ESG legislation claims "...the rise of ESG investing [which] sacrifices returns at the altar of...woke agendas," referring to ESG standards as "woke." Furthermore, they state ESG investing "[drives] up costs for consumers in the name of diversity and [sidelines] hardworking Americans by threatening their livelihoods" (Spectrum News Staff, 2022). In a statement the Texas Republican Comptroller said, "The environmental, social and corporate governance movement has produced an opaque and perverse system in which some financial companies no longer make decisions in the best interest of their shareholders or their clients," (Freedman, 2022).

> "The models and procedures from the study of 70 U.S. public equity ESG funds and the isolated Parnassus Core Equity ESG Fund provide conclusive empirical evidence that U.S.-based public equity ESG funds produce greater risk-adjusted returns than the market."

This paper seeks to assess the validity of such statements concerning ESG by comparing the financial returns of the U.S. public equity ESG funds offered by the Forum for Sustainable and Responsible Investment's (SIF) — the ESG Composite —– institutional member firms to the S&P 500 total return index on several metrics including cumulative return, annualized return, and Sharpe ratio. It then compares the largest individual fund comprising the ESG Composite — the PRBLX portfolio — to the S&P 500 total return index on the same metrics. Next, it compares the ESG Composite and the PRBLX portfolio to the global mutual fund universe on annualized returns, annualized Sharpe ratios, annualized alphas, and annualized information ratios. Lastly, it conducts a factor analysis of the ESG Composite and the PRBLX portfolio to draw investment insights.

This paper proceeds as follows: section 3 reviews the literature, section 4 presents the data and empirical strategy, section 5 reviews the results, and section 6 concludes.

Literature Review

There are numerous papers that study the link between ESG performance and financial performance. For instance, Friede et al. (2015) used evidence from over 2,000 studies of ESG and financial performance and found that 90% of these studies contain a non-negative relationship that remains approximately the same over time. While this study does find that there is a more positive relationship between ESG and the financial performance of bonds, it does not deny the existence of a positive relationship between ESG and the financial performance of equities.

Whelan et al. (2022) build upon Friede et al. (2015) by aggregating over 1,000 studies written between 2015 and 2020. In the corporate studies primarily focused on financial performance, they found that at least 58% of them found a positive relationship between ESG and financial performance. In studies focused on risk-adjusted metrics, 33% of them found a positive relationship, 26% found a neutral relationship, 28% found mixed results, and only 14% found a negative relationship.

Preston and O'Bannon (1997) established several theoretical points of view that express a direction and reason for the relationship between ESG and financial performance. These hypotheses have since been widely adopted in literature, and are as follows: social impact hypothesis, supply and demand hypothesis, trade-off hypothesis, available resources hypothesis, and the managerial opportunism hypothesis.

The social impact hypothesis posits that higher levels of corporate social responsibility (CSR) lead to improved financial performance. This relationship is suggested in the instrumental theories of Garriga and Melé (2004), including the well-known stakeholders' theory, which states that corporations should strive to do right by all of their stakeholders (including employees, customers, suppliers, local communities, environmental groups, and governmental groups) to achieve true lasting success. Stakeholders' theory

is diametrically opposed to shareholders' theory, which states that a company's sole motivation should be to advance its shareholders' interests (McAbee, 2022). The social impact hypothesis believes that CSR procures financial performance by creating competitive advantages in the market (Jain et al., 2017), improving reputation (Fombrun and Shanley, 1990), building brand image (Murray and Montanari, 1986), and strengthening legitimacy (Hart and Christensen, 2002). In terms of reputation, Cornell and Shapiro (1987) find that when a company ignores the preferences of interest groups, it damages its own reputation, which inversely increases risk premium and overall financial risk. On the other hand, Cornell and Shapiro maintain that the cost of CSR is almost negligible to its potential benefits.

> "U.S. public equity ESG funds produce greater risk-adjusted returns than the market itself."

Most outstanding literature reviews support the social impact hypothesis, such as Griffin and Mahon (1997), which found that 33 out of 51 reviewed studies describe a positive correlation between CSR and financial performance. Following this trend, Frooman (1997) found that companies deemed to be irresponsible in their social policies obtained lower profits. Orlitzky et al. (2003) obtained similar results when conducting a meta-analysis of over 50 studies between 1970 and 1997, confirming a positive relationship between socially responsible behavior and financial performance. However, Godfrey et al. (2009) noted that the reason for a positive correlation varied between results, such as the positive effect of reputation, or the different methods of measuring CSR and financial performance. Adding to the supportive findings of Orlitzky et al. (2003), Allouche and Laroche (2005) found in an analysis of 82 studies spanning the U.S. and the U.K. that CSR has a positive effect on financial results, with a greater effect measured in the U.K. Tang et al. (2012) also validated the social impact hypothesis, but only when the CSR is adopted as a consistent strategy. In emerging economies, Mishra and Suar (2010) found that CSR strategies prioritizing stakeholders' theory can be profitable to Indian firms. Hebb et al. (2016) revealed empirical evidence about the positive relationship between CSR and aspects such as the degree of CSR awareness and stakeholder pressure in Spain. Therefore, there exists a positive relationship between CSR and financial performance, where CSR is the driving force or independent variable of the relationship.

The supply and demand hypothesis posits that there is no clear link between social and financial performance, as pointed out by McWilliams and Siegel (2001). Roman et al. (1999) found support for this hypothesis in just 14 of 52 studies reviewed dealing with this relationship. Margolis and Walsh (2003) found evidence for a weak relationship between CSR and financial results in an analysis of 127 studies, in which 31 found it to be either absent or nonsignificant. Van Beurden and Gossling (2008) found nine studies with neutral results, including those by Bowman (1978), Aupperle et al. (1985), Freedman and Jaggi (1986), Fombrum and Shanley (1990), Ruf et al. (2001), and Seifert et al. (2004). There were also studies that found a relationship but reached contradictory conclusions, finding that the relationship is either indeterminate or neutral, according to whether it is positive or negative. Griffin and Mahon (1997) found nine studies with mixed results out of 51, and in the work of Margolis and Walsh (2003) there were 23 out of 27.

According to the trade-off hypothesis, higher CSR levels lead to lower financial performance. Friedman (1970) argues that businesses have no responsibilities other than achieving the highest possible profits, so investing in CSR involves an extra cost that places a company at a disadvantage in relation to its competitors and brings in lower profits. Very few authors found a negative relationship between CSR and financial results in their investigations. Some of the most important empirical studies that did so were those by Brammer et al. (2006) and Van der Laan et al. (2008).

The available resources hypothesis links good financial performance with high levels of CSR. According to Waddock and Graves (1997), good financial results mean that money can be invested in CSR, so that high profits could be a good indicator of subsequent good social results.

Of the above-mentioned reviews, Margolis and Walsh (2003) concentrate the most on studies that consider social responsibility as a dependent variable. Of 22 of this type, 16 found a positive correlation, i.e., good financial performance leads to the adoption of CSR; three found the correlation to be nonsignificant, and three more found it to be bidirectional. Studies such as those by McGuire et al. (1988, 1990) provide empirical support for this hypothesis.

The managerial opportunism hypothesis, empirically validated in the work of Posner and Schmidt (1992), considers

> "Adopting holdings strategies of the PRBLX portfolio can offer the greatest financial benefits of ESG investing."

that higher financial performance levels lead to lower CSR levels. Authors such as Person and O'Bannon (1997) argue that directors may act to increase their personal benefits and reduce investment in CSR when profit levels are high. Similarly, if profits are low, directors may attempt to justify the situation by blaming ambitious social programs.

Although a substantial number of studies show a positive relationship between financial performance and individual companies exhibiting CSR strategies, few look at the landscape of ESG funds, which compile such companies to build an entire portfolio. Furthermore, the scope of "positive financial performance" is loosely defined and often differing in many studies, with no standard benchmark for returns to be compared with. Some studies have compared ESG funds with a benchmark, but these funds also hold international equities or bonds and inaccurately compare them to the U.S. public equity-based S&P 500. This study compares a list of 70 U.S. public equity ESG funds to the S&P 500 to maintain the "apples-to-apples" theme and generate tangible, consistent metrics of performance.

Data and Empirical Strategy

U.S. SIF

The ESG Composite is formed by filtering public equity ESG funds offered by the U.S. SIF member firms. The U.S. SIF is supported by the U.S. SIF Foundation, a 501(c)(3) nonprofit organization that seeks to educate, research and propel the mission of U.S. SIF (US SIF, 2022). It is the leading voice in advancing sustainable investing across all asset classes with the mission to "rapidly shift investment practices toward sustainability, focusing on long-term investment and the generation of positive social and environmental impacts." Institutional members of the U.S. SIF manage $5 trillion in assets under management (AUM), and include investment management and advisory firms; mutual fund companies;

Table 1. Summary Statistics for the ESG Composite Versus the S&P 500

Summary Statistics	ESG Composite Return	S&P 500 Total Return
Cumulative Return (01/01/2005 - 12/31/2020)	319.19%	325.06%
Annualized Return	10.04%	10.13%
Standard Deviation	14.51%	16.40%
Downside Deviation	12.45%	22.85%
Sharpe Ratio	0.60	0.54
Sortino Ratio	0.70	0.39
Active Return (vs. S&P 500 Total Return)	-0.09%	N/A
Tracking Error (vs. S&P 500 Total Return)	3.45%	N/A
Information Ratio (vs. S&P 500 Total Return)	-0.03	N/A

Table 2. Summary Statistics for the PRBLX Portfolio Versus the S&P 500

Summary Statistics	PRBLX Portfolio Return	S&P 500 Total Return
Cumulative Return (01/01/2005 - 12/31/2020)	436.10%	325.06%
Annualized Return	11.84%	10.13%
Standard Deviation	14.04%	16.40%
Downside Deviation	10.65%	22.85%
Sharpe Ratio	0.75	0.54
Sortino Ratio	0.99	0.39
Active Return (vs. S&P 500 Total Return)	1.72%	N/A
Tracking Error (vs. S&P 500 Total Return)	4.84%	N/A
Information Ratio (vs. S&P 500 Total Return)	0.35	N/A

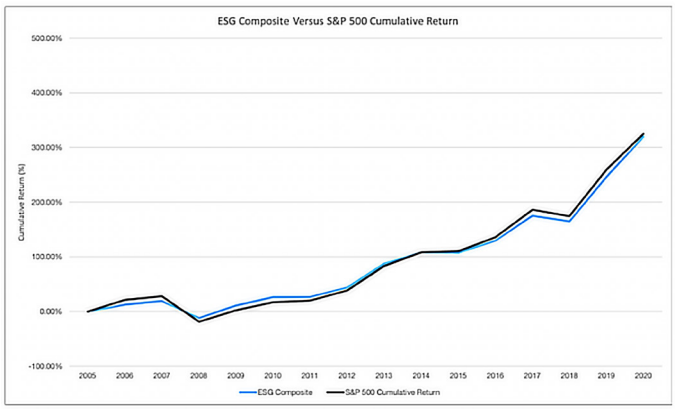

Figure 1. ESG Composite Versus S&P 500 Cumulative Returns

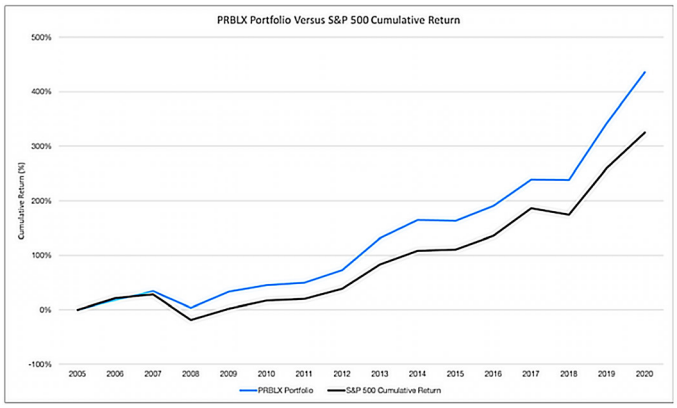

Figure 2. PRBLX Portfolio Versus S&P 500 Cumulative Returns

assets owners and broker-dealers, among others.

ESG Composite

The ESG Composite was created by filtering U.S. SIF Sustainable Investment Mutual Funds and ETFs Chart to all U.S. public equity ESG funds on the database.

ESG Composite, PRBLX, & Mutual Funds Returns Data

Annual total returns of over 23,000 active equity mutual funds through the year 2020 were scraped from YahooFinance and accumulated into one dataset (Kurapatskie & Darnall, 2013).

This dataset is available to the public, along with https://finance.yahoo.com. This dataset was filtered for over 10,000 active equity mutual funds that were operative during some period between January 2005 and December 2020. The ESG Composite was further filtered from this list to the 70 funds from the U.S. SIF database, and annual total returns of each fund from 2005 to 2020 were provided.

Annual total returns data for the PRBLX portfolio were provided by Yahoo finance (Parnassus Core Equity Fund, 2020). Annual total returns data for the S&P 500 total return index were provided by YahooFinance (S&P, 2020). Methods for calculating returns can be found in the appendix.

$$(R_{p,t} - R_{f,t}) = a + \beta * (R_{m,t} - R_{f,t}) + \varepsilon t \qquad (1)$$

$$(R_{p,t} - R_{f,t}) = \alpha + \beta_{MKT} * (R_{m,t} - R_{f,t}) + \beta_{SMB} * SMB_t + \beta_{HML} * HML_t + \varepsilon t \quad (2)$$

$$(R_{p,t} - R_{f,t}) = \alpha + \beta_{MKT} * (R_{m,t} - R_{f,t}) + \beta_{SMB} * SMB_t + \beta_{HML} * HML_t + \beta_{UMD} * UMD_t + \varepsilon t \quad (3)$$

Calculating ESG Composite Returns

Unlike the PRBLX portfolio and S&P 500, the ESG Composite is a list of funds. A simple average or median of list returns were susceptible to high volatility from small funds, so a weighted average based on NAV was used. The total NAV of the ESG Composite was calculated by summing each NAV, and then a proportion was calculated by dividing fund-specific NAV by the sum. Finally, the proportion was multiplied by annual total return for each fund per year, and year-specific values were summed to create NAV-weighted annual total returns for the ESG Composite.

Factor Data and Analysis

In a factor analysis of the ESG Composite and PRBLX portfolio excess returns ($R_{p,t}$ - $R_{f,t}$), several specifications and regressions were provided using popular academic factors, with data from January 2005 to December 2020. This includes the CAPM (Equation 1) regressing the ESG Composite and PRBLX portfolio excess returns on a leverage factor (MKT-Rf) defined by the S&P 500 minus the risk-free 3-month T-bill rate:

Analysis also includes a Fama-French (1993) Three Factor Model (Equation 2) that regresses the ESG Composite and PRBLX portfolio excess returns on a leverage factor (MKT-R_f) in addition to size (SMB) and value (HML) factors obtained from the Ken French data library:

Another specification is provided using the Carhart (1997) Four Factor Model (Equation 3) that includes a momentum factor (UMD), also obtained from the Ken French data library:

In separate specifications, this study also regresses the

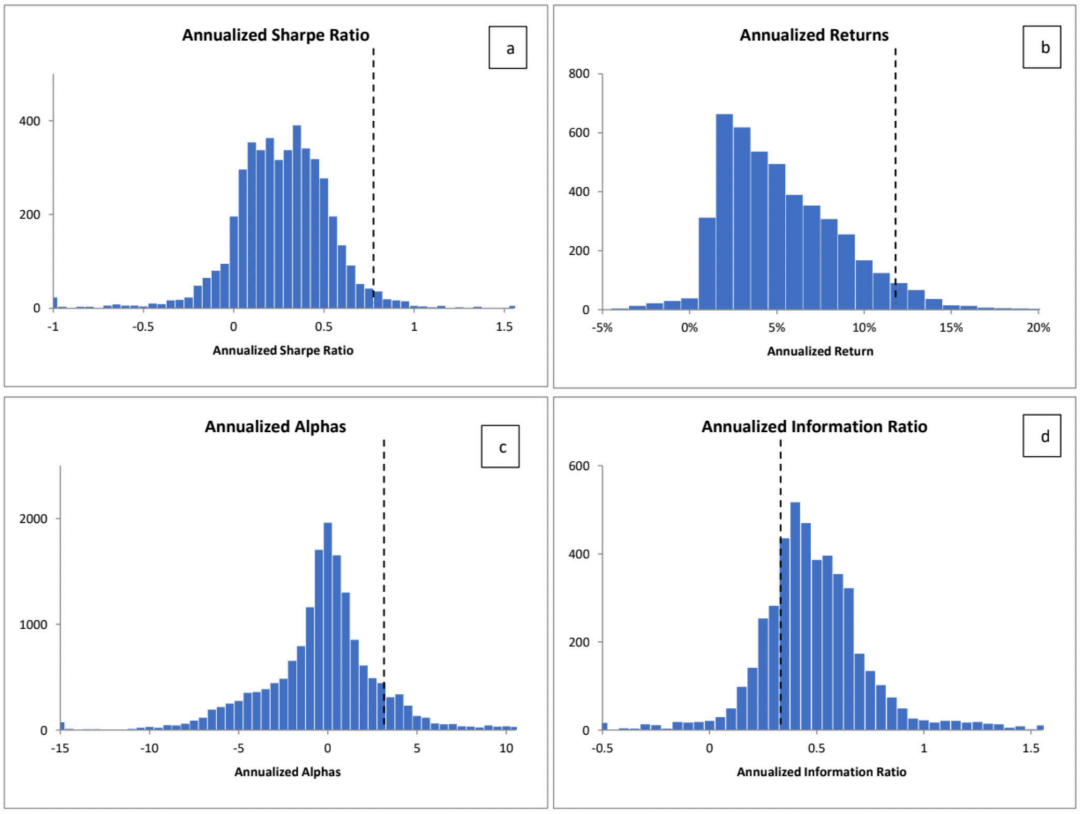

Figure 3. ESG Composite Compared to YahooFinance Mutual Fund Universe (Jan. 1, 2005 – Dec. 31, 2020)

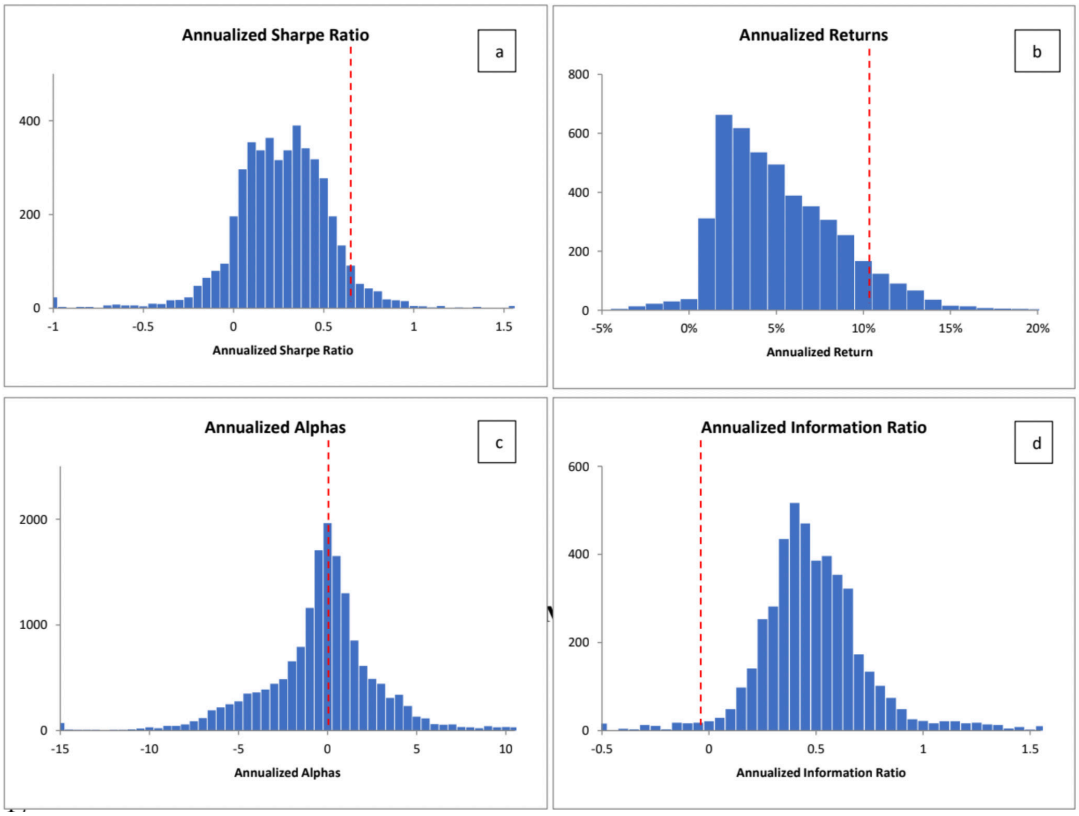

Figure 4. PRBLX Portfolio Compared to YahooFinance Mutual Fund Universe (Jan. 1, 2005 – Dec. 31, 2020

PRBLX portfolio excess returns on the Frazzini and Pedersen (2014) Betting-Against-Beta factor and the Asness et al. (2013) Quality Minus Junk (QMJ) factor.

Synthetic Portfolio Construction

Systematic synthetic portfolios are constructed from the same regressions of monthly returns in Table 3 and Table 4, namely the Four Factor regression using data over the entire time period of January 2005 to December 2020. The portfolio is rebalanced annually at year-end to keep constant weights. The explanatory variables are the monthly returns of the standard size, value, and momentum factors.

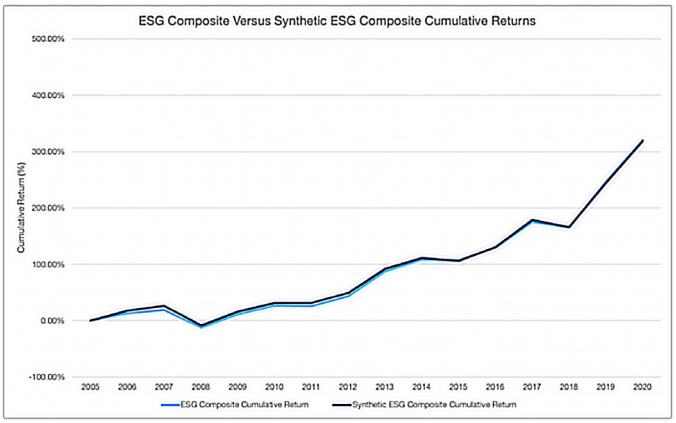

Figure 5. ESG Composite vs. Synthetic ESG Composite Cumulative Returns

Results

ESG Composite versus S&P 500

Table 1 displays the side-by-side performance of the ESG Composite and the S&P 500 total return index.

On cumulative return, the ESG Composite is less than the S&P 500, at 319.91% and 325.06%, respectively. Annualized return of the ESG Composite is approximately equal to the S&P 500, with a difference of 0.09%. Standard deviation of the ESG Composite is less than the S&P 500, with a difference of 1.89%. Downside deviation of the ESG Composite is much lower than the S&P 500, with a difference of 10.4%. Sharpe ratio of the ESG Composite is slightly greater than the S&P 500, with a difference of 0.06. However, the Sortino ratio of the ESG Composite is nearly double the S&P 500, with a difference of 0.31. Active return and Information Ratio of the ESG Composite are both negative, but tracking error is relatively low at 3.45%.

Figure 1 below displays the ESG Composite and S&P 500 cumulative returns tracked from 2005 to 2020. Table 2 displays the side-by-side performance of the PRBLX portfolio and the S&P 500 total return index.

Table 3. ESG Composite Exposures: What Kind of Companies Do U.S. Public Equity ESG Funds Own?

	CAPM	Fama-French (1993)	Carhart (1997)	Frazzini Pedersen (2014)	Asness Frazzini Pedersen (2013)
Alpha	0.497% (0.491)	0.074% (0.932)	0.283% (0.754)	0.226% (0.716)	-0.283% (0.738)
MKT-Rf	**0.834***** (~0)	**0.868***** (~0)	**0.850***** (~0)	**0.951***** (~0)	**0.979***** (~0)
SMB	N/A	-0.066 (0.543)	-0.097 (0.397)	**-0.163*** (0.063)	-0.123 (0.201)
HML	N/A	0.031 (0.376)	0.026 (0.457)	0.013 (0.601)	0.002 (0.955)
UMD	N/A	N/A	-0.031 (0.338)	-0.027 (0.235)	-0.030 (0.196)
BAB	N/A	N/A	N/A	**-2.218***** (0.004)	**-2.242***** (0.005)
QMJ	N/A	N/A	N/A	N/A	0.930 (0.381)

The PRBLX portfolio has a significantly greater cumulative return than the S&P 500, at 436.10% versus 325.06%, respectively. Annualized return of the PRBLX portfolio is also greater than the S&P 500, with a difference of 1.71%. Standard deviation of the PRBLX portfolio is less than the S&P 500, with a difference of 2.36%. Downside deviation of the ESG Composite is significantly lower than the S&P 500, with a difference of 12.2%. The Sharpe ratio of the ESG Composite is greater than the S&P 500, with a difference of 0.21. Furthermore, the Sortino ratio of the PRBLX is over double the S&P 500, with a difference of 0.6. Active return and Information Ratio of the PRBLX portfolio are both positive, indicating outperformance over the S&P 500. Tracking error is still low at 4.84%.

Figure 2 displays the PRBLX portfolio and S&P 500 cumulative returns tracked from 2005 to 2020.

Versus Global Mutual Fund Universe

Figure 3 shows where the ESG Composite (vertical red dashed line) compares against the distribution of annualized returns, Sharpe ratios, alphas, and information ratios of all actively managed equity funds operative between 2005 and 2020.

Figure 3a shows the ESG Composite in the higher ranges of annualized Sharpe ratio amongst the mutual fund universe. Figure 3b shows the ESG Composite in the higher ranges of annualized returns amongst the mutual fund universe. Figure 3c shows the ESG Composite near the center of the annualized alphas amongst the mutual fund universe. Figure 3d shows the ESG Composite near the lower ranges of annualized information ratios amongst the mutual fund universe.

Figure 4 shows where the PRBLX portfolio (vertical black dashed line) compares against the distribution of annualized returns, Sharpe ratios, alphas, and information ratios of all actively managed equity funds operative between 2005 and 2020.

Figure 4. PRBLX Portfolio Compared to YahooFinance Mutual Fund Universe (Jan. 1, 2005 – Dec. 31, 2020)

Figure 4a shows the PRBLX portfolio in the higher ranges of annualized Sharpe ratios amongst the mutual fund universe. Figure 4b shows the PRBLX portfolio in the higher ranges of annualized returns amongst the mutual fund universe. Figure 4c shows the PRBLX portfolio near the center of the annualized alphas amongst the mutual fund universe. Figure 4d shows the PRBLX portfolio near the lower ranges

Table 4. PRBLX Portfolio Exposures: What Kind of Companies Does the PRBLX Portfolio Own?

	CAPM	Fama-French (1993)	Carhart (1997)	Frazzini Pedersen (2014)	Asness Frazzini Pedersen (2013)
Alpha	**2.66%** (0.039)	2.26% (0.133)	**2.66%*** (0.086)	**2.60%*** (0.061)	1.64% (0.357)
MKT-Rf	**(0.779***** **(**~0)	**0.815***** (~0)	**0.778***** (~0)	**0.898***** (~0)	**0.950***** (~0)
SMB	N/A	-0.195 (0.284)	-0.255 (0.177)	**-0.332*** (0.063)	-0.258 (0.194)
HML	N/A	0.018 (0.744)	0.009 (0.871)	- 0.007 (0.8916)	-0.027 (0.625)
UMD	N/A	N/A	-0.061 (0.247)	-0.056 (0.2268)	-0.063 (0.196)
BAB	N/A	N/A	N/A	**-2.609*** (0.0617)	**-2.655*** (0.064)
QMJ	N/A	N/A	N/A	N/A	1.748 (0.421)

of annualized information ratios amongst the mutual fund universe.

Factor Attribution

Table 3 displays the results of factor regression of the ESG Composite.

Alpha values for the Capital Asset Pricing Model (CAPM), Fama-French, Carhart, Frazzini Pedersen, and Asness-Frazzini-Pedersen equations are statistically insignificant. Thus, no conclusions can be drawn from them. Traditional leverage factor betas (MKT- Rf) are statistically significant on the 1% scale across all equations, ranging from 0.834 to 0.979. Small minus big (SMB) factor beta is statistically significant at the 10% scale, with a negative value of -0.163. Betting-against-beta (BAB) factor betas are statistically significant at the 1% scale in both equations that incorporate them, with values less than -2.2.

Table 4 displays the results of factor regression of the ESG Composite.

Alpha values for the CAPM, Carhart, and Frazzini-Pedersen equations are statistically significant, with values around 2.6%. Traditional leverage factor betas (MKT- Rf) are statistically significant on the 1% scale across all equations, ranging from 0.779 to 0.950. Small minus big (SMB) factor beta is statistically significant at the 10% scale, with a negative value of -0.332. Betting-against-beta (BAB) factor betas are statistically significant at the 1% scale in both equations that incorporate them, with values less than -2.6.

Synthetic Portfolio Adjustment

Figure 5 shows calendar-time returns of a synthetic portfolio of the ESG Composite that uses the factor loadings as estimated from factor regression analysis.

Figure 6 shows a zoomed view of the calendar-time returns of the synthetic ESG Composite portfolio.

The synthetic ESG Composite slightly outperforms the ESG Composite's actual cumulative returns for the entire period, particularly between 2005 and 2012, with an approximately 6% improvement in 2007 and an approximately 5% improvement in 2010.

Figure 7 shows calendar-time returns of a synthetic portfolio

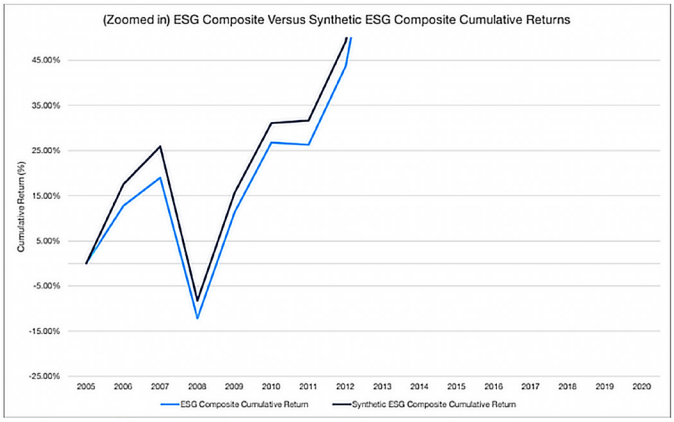

Figure 6. (Zoomed in) ESG Composite vs. Synthetic ESG Composite Cumulative Returns

of the PRBLX portfolio that uses the factor loadings as estimated from factor regression analysis.

The synthetic ESG Composite slightly underperforms the PRBLX portfolio's actual cumulative returns for the entire period, particularly between 2005 and 2015, with an approximately 10% decrease in 2013 and an approximately 15% decrease in 2015.

Interpretation

ESG Composite

Due to statistically insignificant differences in cumulative return and annualized return, it can be assumed that the ESG Composite produces approximately equal returns as the S&P 500. This is supported in Figure 1, as there is little deviation between cumulative returns at any point in the period of analysis. In a worst-case scenario, the ESG Composite minimally underperforms, as active return and information ratio are only slightly negative. Ultimately, it can be concluded that both U.S. public equity ESG funds and the S&P 500 will produce a return of approximately 10% per year. On the other hand, the volatility of the ESG Composite is significantly less than the S&P 500, as shown by the lower standard and downside deviation. The S&P 500's particularly high downside deviation implies that, compared to U.S. public equity ESG funds, investing in the S&P 500 produces a greater risk of negative returns. The ESG Composite produces greater risk-adjusted returns due to lower volatility combined with equal returns. This point is supported by the fact that the Sharpe ratio and the Sortino ratio of the ESG Composite are higher than the S&P 500. The ESG Composite's particularly high Sortino ratio implies that, compared to the S&P 500, investing in U.S. public equity ESG

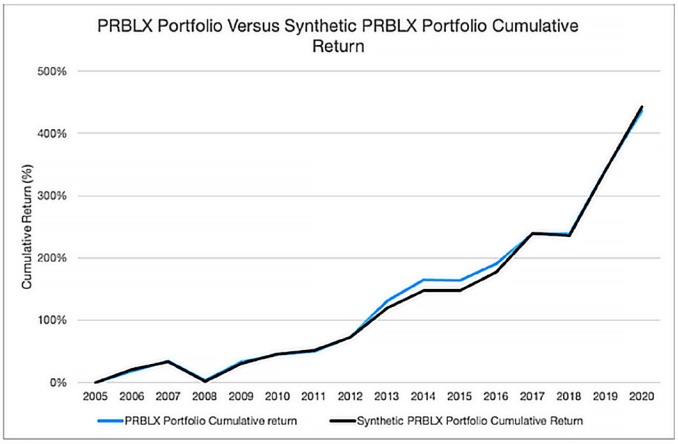

Figure 7. PRBLX Portfolio vs. Synthetic PRBLX Portfolio Cumulative Returns

funds produces much greater risk-adjusted returns.

Figure 3 shows the ESG Composite in the higher ranges of annualized Sharpe ratio and annualized returns of the global mutual fund universe. This implies that the U.S. public equity ESG funds generally outperform mutual funds on both a returns and risk-adjusted returns basis. Annualized alpha values of the ESG composite are average compared to the mutual fund universe, indicating that the U.S. public equity ESG funds offer just as much outperformance over the market as the average mutual fund. Supplementing average to above-average returns with exceptional risk-adjusted returns implies that U.S. public equity ESG funds offer much more stability than their mutual fund competitors.

As described in the introduction, the primary reason for ESG bans in the U.S. is the concern of fewer returns. This analysis dissuades such sentiment by proving that U.S. public equity ESG funds produce greater risk-adjusted returns than the market itself.

Factor analysis of the ESG Composite finds statistically insignificant alpha values across all equations, suggesting that U.S. public equity ESG funds do not deviate much in returns from the S&P 500. Across all specifications, the results demonstrate slight leverage (investing in the market portfolio), with traditional leverage factor betas near one, especially in the Asness-Frazzini Pedersen equation. The relatively low tracking error of the ESG Composite supports this idea, along with Figure 1. In the Frazzini-Pedersen equation, the study finds that the ESG Composite has more exposure to large caps given the negative SMB factor. When including the Frazzini and Pedersen (2014) Betting-Against-Beta factor and the Asness et al. (2013) Quality Minus Junk (QMJ) factor, this study finds further evidence that the ESG Composite tilts toward large cap stocks and stocks with high beta exposure.

PRBLX Portfolio

With significant differences in cumulative return and annualized return, it can be assumed that the PRBLX portfolio produces much greater returns than the S&P 500. This is shown in Figure 2, as the PRBLX portfolio begins deviating from the S&P 500 in 2007 and continues through 2020. Both active return and information ratio are positive as well, indicating that the PRBLX portfolio minimally outperforms in a worst-case scenario. Ultimately, it can be concluded that the PRBLX portfolio will produce greater returns than the S&P 500's return of approximately 10% per year. Still, the volatility of the PRBLX portfolio is significantly less than the S&P 500, as shown by the lower standard and downside deviations. The drastic difference between downside deviations of the PRBLX portfolio and the S&P 500 implies that, compared to the Parnassus Core Equity Fund, investing in the S&P 500 produces a greater risk of negative returns. Lower volatility combined with greater returns means the PRBLX portfolio produces exceptionally greater risk-adjusted returns, an assertion supported by the fact that Sharpe ratio and Sortino ratio are larger than the S&P 500. The PRBLX portfolio's Sortino ratio is over double the S&P 500, implying that investing in the Parnassus Core Equity fund produces greater risk-adjusted returns than the S&P 500.

Figure 4 shows the PRBLX portfolio in the highest ranges of annualized Sharpe ratio, annualized returns, and annualized alpha values of the global mutual fund universe. This finding implies that U.S. public equity outperforms mutual funds from a returns and risk-adjusted basis, as well as exceeds mutual funds in their own outperformance over the market. The information ratio of the PRBLX portfolio is near average but still positive, indicating the PRBLX portfolio provides at least as much outperformance as the S&P 500.

All of these results dissuade anti-ESG sentiment in the U.S. spurred by concern over returns by proving that the PRBLX ESG fund produces significantly greater returns and risk-adjusted returns than the market and the global mutual fund universe. Furthermore, the findings suggest that adopting holdings strategies of the PRBLX portfolio can offer the greatest financial benefits of ESG investing.

Factor analysis of the PRBLX portfolio finds statistically significant alpha values in the CAPM, Carhart, and Frazzini-Pedersen equations of around 2.66%. This implies that the PRBLX portfolio produces expected outperformance over the S&P 500 of at least 2%. Compared to the ESG Composite, traditional leverage factor betas for the PRBLX portfolio are lower, indicating the Parnassus Core Equity fund is less levered to the market than most U.S. public equity ESG funds. On the other hand, SMB value in the same specification is nearly twice as negative as the ESG Composite, indicating the Parnassus Core Equity Fund has a much greater preference for large caps than most U.S. public equity ESG funds. Furthermore, BAB factor betas are more negative than the ESG Composite, indicating the Parnassus Core Equity fund has a greater preference for high beta stocks than most U.S. public equity ESG funds.

Investment Insights

The composite of U.S. public equity ESG funds produced greater risk-adjusted returns than the S&P 500, with a slight underleverage to the market, yet a preference for large cap, high beta stocks. However, there is potential for optimization if these preferences are strengthened. Such improvement is shown in the synthetic portfolio construction of the ESG Composite (Figure 6), which used factor loadings from ESG Composite regression to create 5-6% greater returns in certain years. A real-life example of this optimization is through the Parnassus Core Equity Fund, which maximized such outperformance over the S&P 500 with a more pronounced underleverage to the market, and a stronger preference for large cap and high beta stocks. Synthetic portfolio construction of the Parnassus Core Equity Fund shows that it cannot be optimized any further, as the factor-derived model produced 10-15% worse returns than the actual portfolio in certain years.

As a result, it can be concluded that the most valuable returns in ESG investing come from prioritizing established, high cash flow companies that outperform during periods of economic growth and are stable during contractions. Holdings data of the Parnassus Core Equity Fund support such insight, with companies like Microsoft, Apple, and Alphabet of the largest selections.

Conclusion

The models and procedures from the study of 70 U.S. public equity ESG funds and the isolated Parnassus Core Equity ESG Fund provide conclusive empirical evidence that U.S.-based public equity ESG funds produce greater risk-adjusted returns than the market. This counters anti-ESG sentiment claiming U.S. ESG funds produce worse financial returns, and builds upon previous literature that found a positive correlation between CSR and financial performance. Factor analysis reveals that preference for large cap, high-beta stocks that outperform during periods of economic expansion will produce the greatest financial returns in the U.S. public equity ESG space, as shown by analysis of the Parnassus Core Equity Fund. This means that investing in blue chip, high cash flow companies like Microsoft, Apple, and Alphabet will produce the greatest financial returns while balancing ESG criteria.

The shortcomings of this study extend to data collection procedures and testing methodology. Although the U.S. SIF provides a significant portion of U.S. public equity ESG funds, an analysis of all funds in the space would provide a more accurate representation of the relationship between US public equity ESG funds and the S&P 500. However, creating such a dataset would require significant effort to analyze individual firms' investment processes. Furthermore, the factor regression produced mostly statistically insignificant results, which could be optimized, but ultimately rejects returns-based claims from anti-ESG legislators by showing that currently ESG funds avoid downside risk.

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