THE QUARK

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What is value? Physics-Informed Economics

By William Kariampuzha

Philosophers and economists have pondered value and its origins for centuries. Some say that they value diamonds, land, or rare Pokémon cards. Others say that they value family, time, or wisdom. Dictionaries state it's what we find useful and businessmen say money. All of these are fascinating topics, but this article will stay within the scope of economics.

Tyler Cowen delves into the question of "where does value come from?" by explaining a hypothetical Crusonia plant. This plant automatically grows and reproduces every year, yielding several apples without tending and mild input of some sun and rain which comes anyway. Cowen states that it "may sound unrealistic or a bit silly," but is this so far from the truth? Didn't dicotyledons reproduce and produce free fruit before humans stepped onto this Earth? Did our human ancestors not just emerge from foraging and gathering free food?

However, while Cowen uses this as a philosophical example to explain where value could come from in our complex present world, he misses the more fundamental. I propose that a physics-centered approach to economics can attempt to answer these questions.

What is value?

In attempting to answer this question with physical principles, we need to take a detour into order and entropy. Order is a concentration of mass or information that has the ability to do work. Some of its properties include predictability or calculability. For example, the sun is an ordered collection of

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About The Quark

The Quark is a monthly newsletter produced by the Public Relations Committee of the Texas Tech chapter of the Society of Physics Students (SPS). Our goal is to help new students become more familiar with the Physics Department and provide returning students more insight on aspects of the department they might not have been aware about.

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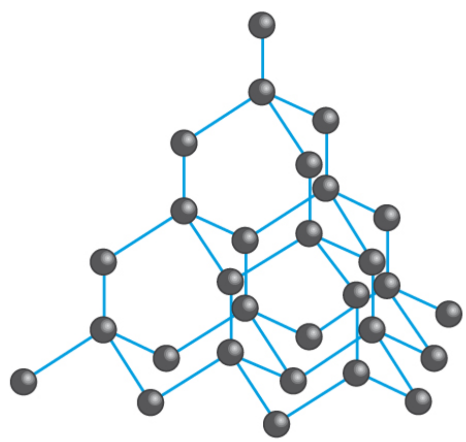
hydrogen atoms that can do nuclear fusion at a fairly predictable rate to release atomic energy and transfer it to the Earth as electromagnetic radiation. But our sun, like any lightbulb, fire or thermonuclear reactor, will eventually run out of its fuel. Entropy is the grim reaper that reduces the order of the sun, contributing to its inevitable demise.

Entropy is formally defined as S=kBln where kB is the Boltzmann constant and is the number of microstates in the system of description. A microstate describes the position and momenta of all of the particles in the system. The number of microstates in a diamond could be calculated as the number of atoms multiplied by the 3 degrees of vibrational freedom that each carbon atom has (disregarding a Boltzmann distribution of vibrational momenta and all subatomic particles for simplicity). This is possible because pure diamond has a rigid tetrahedral carbon structure so the positions nor translational or rotational momenta of the atoms would change. However, the number of microstates of gaseous carbon dioxide in a jar would be astronomically higher because the sheer number of possible positions of a single atom would be the volume of the jar divided by the nearly infinitesimally small volume of the CO_2 molecule. This is before accounting for the combinations of possible positions for more than one molecule or the Boltzmann distribution of the rotational, vibrational, and translational degrees of freedom in each of those particles.



The Tetrahedral Structure of Diamond

To this point we have discussed entropy independent of time. In nature, the number of (possible) microstates is changing all of the time. Change in entropy is denoted as Delta S; the Second Law of Thermodynamics tells us that at all times Delta S_universe > 0, however, it does not state that at all times Delta S_local>0. This means that entropy can decrease in a local, closed system. To continue our previous example, consider how diamonds are formed.

The carbon comprising natural diamonds originates from deposition of disordered liquid metal-carbon (Fe-Ni-C-S, not coal contrary to popular belief) deep in our Earth's mantle [2]. Thus, whenever the small amount of carbon is deposited into the rigid tetrahedral matrix, the number of microstates available for the carbon to occupy decreases - ergo entropy decreases locally. However, the system does not disobey the second law of thermodynamics. The total entropy of the universe still increases due to a number of factors, including 1) the Fe-Ni-C-S liquid metal composite loses carbon, creating a slurry of Fe-Ni-C-S and Fe-Ni-S (or some other combination) in the mantle which increases disorder, 2) as those carbon are not liquid any more, they cannot contribute to convection in a form that we harvest as geothermal energy, and most notoriously 3) the heat concentrated in a few molecules during the reaction transferred itself inefficiently and has now increased the momenta of a greater number of previously slower molecules.

Now, we have covered a little background on entropy, you may ask “What does this have to do with value or economics?” The reason I chose a “girl’s best friend” was hopefully apt because I ask that you make a leap with this bold hypothesis: I posit that a localized decrease in entropy is value.

Where does value come from?

Although GDP is not a perfect measure of value because it is a monetary calculation which is mutable and not proportional to intrinsic value, even inflation-adjusted GDP has seen global increases of economic output [3] in the past two hundred years. So where did this increase of value come from?

As my definition of value is based upon entropic processes, we can readily answer this question. Tracing the origin of economic value, we see that historical wealth increases can come about via two types of localized entropic processes:

1. Increase of occurrences or magnitude of localized entropic decrease coupled with overall entropic increase.
2. Increase in efficiency of matter or information conversion.

(1) implies that we are either creating more value through novel processes or we are creating value more often. This is good right? In some ways yes! However, remember that this is coupled with total entropy increase in the universe. Thus, this implies that total disorder increases in ways that can negatively affect us. A prime example of this is climate change. Fossil fuels hold value by virtue of the arrangement of carbon bonds and reduced entropy compared to carbon dioxide and economically viable concentration in mines. In humanity’s bittersweet tribute to industrialism, we rapidly increased the occurrences and magnitude of converting that atomic and chemical order into electricity, subsequently rapidly increasing entropy.

This story plays out again with commercial mega cattle ranches increasing the number of cattle to supply the world with beef. As any living thing forms order from its environment, it is a localized reduction in energy coupled with massive increases in total entropy. In our case, the value that came from grass was converted into heat and meat for the cow, with the entropic byproduct of methane and carbon dioxide. These, and many similar cases, led to measurable increases in disorder in our atmosphere (release of chlorofluorocarbons, CO_2, and CH_4) and oceans (dissolved CO_2 forms bicarbonate in water which destroys coral systems and alters pH).

Thankfully, we have hope due to the implications of (2). While it is true that everything we do, including existing, contributes to the inevitable entropic increase in our universe, we can increase our efficiencies.

The Second Law of Thermodynamics tells us that Delta S_universe > -Delta S_local, but it does not say that -Delta S_local is proportional to Delta S_universe. This means that with greater efficiency, local entropy can decrease at the same magnitude as prior to optimization, while total entropic increase reduces in magnitude or that local entropy decreases with greater magnitude (more value created), but total entropic increase stays the same in the process. For instance, the Haber-Bosch process directly decreases entropy by fixing four atmospheric molecules into two molecules of ammonia. This gave plants a previously growth-limiting factor which allowed us to create food on a much greater scale than was previously possible. This single handedly contributed to massive economic and lifestyle improvements and a reckoning for Malthusian harbingers. The Bessemer process for steel production, the creation of mass public transit, the birth of the internet, renewable energy generation, I won't delve into details but all of these provide us with increased efficiency so that for every localized entropic decrease, we don't exorbitantly increase the overall entropy of the Earth's system.

Although we have looked at the two types of processes that lead to increases in value and their implications on society, we still have not answered the question of where value originates. Using this definition, I propose that essentially all value on Earth originates from the natural resources of this Earth and the energy of the sun. Take life for example. As I stated earlier, every living thing is a localized reduction in entropy wherein the resources (C, P, N, O, H, Mg, Fe, etc.) to build a life form come from Earth, and the energy comes from the sun as electromagnetic radiation. Therefore, all the value in food that we eat comes from the Earth and the Sun. If we are sustained by food, then most (or all) of our value as human beings, comes from the Sun.

Whenever we erect a building, taking raw building materials and converting them into an architectural masterpiece, we locally reduce the entropy of the system. However, we must always remember that the dust, the mines, the transportation of those materials all contributed to the entropic increase of Earth's system.

So where does the sun's value come from? It comes from the massive local (on a solar system level) reduction in entropy due to gravity bringing moles of moles of hydrogen atoms together for nuclear fusion. Then, it makes our way to us via a constant, ordered amount of EM radiation that increases the entropy of the Universe. Earth, a minuscule cross sectional area of the sun's expanding sphere of energy, merely absorbs some of that great value and converts it to its own localized reduction in entropy. Thus, nearly everything that is of value comes from either the Earth or the Sun. Philosophically, we should be grateful for what we have.

Conclusion

Once again, I propose that value is a localized decrease in entropy. To find where it comes from, one needs only to search for reductions in local entropy throughout and into time. While I boldly propose this hypothesis, I anticipate criticisms or questions from anyone who has made it this far.

Economics and physics may seem like an unlikely pair, but both are on their own search for truth. Physics is governed by natural laws and statistical distributions that describe phenomena such as entropy. Economics ultimately aims to understand a human enterprise so while I hope that physics, specifically a qualitative study of entropy, can shed light on intrinsic value in economic systems, I accept that interdisciplinary analogies have limitations.

In future iterations or different publications, I should hope to expand on this hypothesis by establishing semantic boundaries and the connection to money. Furthermore, I hope to probe deeper into nuclear fusion and fission, implications for humans, connections to John's Wheeler's "it from bit" proposition, and the diamond-in-the-rough of the notion of reversibility and CP violation.

Molten Salt Energy Storage

By Akash Maheshwari

One of the greatest problems of the 20th and 21st century is the efficient and secure storage of energy. For centuries, humans have developed a variety of different ways to store energy. From placing water at a greater altitude to the revolutionary inventions of lithium-ion, nickel-cadmium and lead-acid batteries, humans have constantly sought ways to make energy readily available and easy to access. Renewable energy sources are promising, but these sources of energy may not correspond properly with energy demands. Perhaps a new type of energy storage device will help our species advance ever further into the future.

Thermal storage appears to be a very promising energy storage device. In this system, energy is stored as heat in either solids or liquids. A high-degree of insulation is necessary to prevent energy from being lost. Different substances may be used for different purposes: water can be cheaply used to store lower temperatures well because it has a high specific heat, phase-change materials can be used because they have a high-energy storage density, etc. However, molten salts appear to be the ideal media because they have low melting points, high boiling points and high heat capacity. Sodium nitrate, potassium nitrate, and a mixture of both chemicals are commonly used. This system can be used to capture solar or nuclear energy and provide consistent access to this energy. When there is an energy demand, the molten salt is deposited into a chamber where the high temperature salt boils water and creates steam that turns a turbine to produce electricity. Once the salt cools, it is pumped back into the heating container where it can be repeatedly used. Although this is the most common way to convert thermal energy into usable electricity, many other different cycles may be used, allowing for increased flexibility.

This technology can be used to capture and store solar energy or nuclear energy. For solar energy, several mirrors are used to focus sunlight onto one central storage tank containing a salt. This salt melts and stores energy for a long period of time. For nuclear energy, molten salt can be used as a coolant or as liquid fuel to achieve higher operational efficiency. As one can understand from the discussion above, molten salt storage systems provide an alternative way to store energy that can be used in many different ways.

Professor Spotlight: Dr. Halyna Hodovanets

By Samuel Cano

Can you tell me about where you grew up and how you entered the world of physics?

I grew up in a very small town in the Carpathian Mountains in Ukraine. I went to middle school during the time when Ukraine had become an independent country. I was introduced to algebra-based physics in around the 7th grade. In later grades, we went over it again with a bit more rigor. It was certainly an interesting subject, but I found mathematics and chemistry to be much more intuitive and I definitely did not see myself doing physics. When I was getting ready to apply for undergraduate programs, I was looking to become a school teacher so I applied to Drohobych State Pedagogical University for mathematics. By fate, I ended up in the physics program (it was physics and mathematics department). It just so happened that my university used to have a research group growing silicon single crystals during the soviet union time. I remember they gave us a tour of the basement and showed us these huge single crystals of silicon. This was really fascinating and, in retrospect, this was where the seed was planted.

After I graduated I was unsure of what I wanted to do next so I stayed at the university working as a support for the physics education laboratory. Then I was able to work as an instructor for a year at the medical college, teaching mathematics and physics to nursing and dental assistant students. It was challenging, but it was a great learning experience. From there, I decided I wanted to further my education and improve my English. The funny thing is that because I was used to the education system in Ukraine, I did not know you could apply to multiple programs at the same time in the same year. Fortunately, I was accepted by the one program that I applied to at Minnesota State University, Mankato (MNSU). There are many challenges for a person that comes to a different country: different culture, bureaucratic and educational systems, to name just a few. One of the biggest challenges was being asked to teach in my first semester, I had no choice but to practice speaking and it ended up being the best thing for me. This, combined with watching TV series, really helped me overcome my fear of speaking English. My MS advisor at MNSU graduated from Iowa State University (ISU) and kept her research connections with the scientists at Ames Laboratory. We would visit Ames to work on material science projects for my MS thesis. I really enjoyed working on these material science and solid state related projects. When a professor from ISU, who would eventually become my PhD advisor, came to give a talk on his research at MNSU, I knew I wanted to go to ISU and do that kind of research with him. After my first year at ISU, I joined my advisor's research group and dived into research.

What kind of research have you been doing in physics?

At MNSU, I was looking at the crystallinity of neodymium-iron-boron ribbons, doped with other materials, that were annealed at different temperatures at Ames Laboratory. At ISU, I ended up working on many different projects. Initially, I was growing single crystals of rare-earth borocarbide superconductors. We were looking at the isotope effect of boron to validate the BCS theory for these superconductors. In another project, I was studying thermoelectric power of Fe-based superconductors, where we applied heat at one end of a sample and measured the voltage drop across the sample generated by the temperature gradient. This measurement can tell a lot about how good the material would be for thermoelectric applications. In the case of Fe-based superconductors, this measurement told us about changes in the Fermi surface that were related to superconductivity. Then, I was using a magnetic field to suppress antiferromagnetic transition in strongly correlated material and looking for a quantum critical point. My last project at ISU was using a chemical substitution to dilute a Kondo lattice compound which led to rather remarkable results. Most of these projects ended up in my PhD thesis.

Although this year is a difficult year to begin building up a lab, I am really excited to start training student researchers. If there are any young future scientists interested in learning more about the work I do, feel free to reach out. A lot of my research is laying the groundwork for understanding quantum materials and their underlying properties, and down the line learning how these properties can be used. For example, quantum initiative is a huge drive for new quantum materials or new materials properties that would lead to successful quantum computers.

After getting your PhD, what were you interested in doing? And how did you end up at TTU?

Well, there are different paths after PhD. If one decides to have an academic career and become a professor at a research university, you need to expand not only your knowledge and skills but also create a new collaborative network. Here, having a few postdoctoral positions is helpful. So, I ended up getting a postdoctoral researcher position at University of Maryland (UMD). UMD worked very well for me because my husband had also gotten a postdoc position there. We both stayed at UMD for almost 6 years during which time we both were promoted to research scientists positions.

While at UMD, I volunteered to substitute teaching an E&M class for my friend who was travelling, and it really reminded me of how much I miss teaching. Eager to start my own research group and learn about the things that I found interesting, I began applying for assistant professor position at different universities. It just so happened that Texas Tech University was looking for someone with my expertise, so here I am. To be honest, I am honored and grateful for this exciting opportunity.

Looking back, do you have a favorite course or lab that you took that was really fun or eye opening?

I had a very good quantum physics professor at ISU, he was gifted at explaining things in an easy way. My favorite lab was actually one that I taught. As a teaching assistant at ISU, I led an intro lab for mostly kinesiology majors and the specific lab I enjoyed was about circuits. The structure of a house with 2 rooms was built in the lab and students had to wire up a switch, a light bulb, and a power outlet (the ones you see in a regular room) so that they would work at 120 V as in a real house. Then, I would power on the circuit breaker and we'd all hope that all connections were made properly or we would end up with a blown fuse. Fun. It was definitely a highlight for me because I could see them understanding not only the material taught but also how it is related to daily life (what's in the wall behind that power outlet?). It was also a cool lab to do myself before teaching.

Do you have any advice for physics students?

I would say with physics you have a lot of choices after you graduate, but my biggest advice would be to start thinking about what you want to do and start preparing and planning early. For grad school, the standardized testing is required and takes a lot of time to prepare for. Learn how to manage your time and level of stress. This will be useful beyond undergraduate level. It can be a lot of fun to go to grad school and take part in many interesting research projects, learn many useful skills. At the same time, it may seem like 5 or 6 years is so far away and you can think about your thesis later. It is easy to lose the track of time. It can be tough if you're entering your last year and still unsure exactly what the centerpiece of your thesis will be. Well, research really is fun, and staying on top of things in regards to your degree will make it a lot less stressful.

Student Spotlight: Madison Howard

By Linka Vinogradova

Can you tell us about why you decided on pursuing physics for your undergraduate studies?

I always loved math. I was never the kid to blurt out the answer first in earlier years but as I got older I ended up teaching myself a lot of math in high school. I soon realized that I was further ahead of my classmates than I expected. Around this time I also was taking AP physics 1. I found it so interesting. Physics is able to apply math in ways that are clever and beautiful. I appreciate how physics gives the "why" to so many mathematical processes.

What made you choose Texas Tech? What do you plan to do after finishing your undergraduate studies?

Growing up in Lubbock I swore up and down that I'd never go to TTU. After touring colleges around the state I realized that TTU was the school that I thought best fit with who I was and what I needed. After I graduate from TTU, I would like to pursue a PhD. I'm not 100% sure where I want to do that yet though. I'm not sure what I want to do after that, either. Regardless, whatever I do, I want to travel. I don't want to live in Texas all my life and I might not even want to live in the US all my life either. I want to have a career that not only allows but values the worldliness that I hope to have. I like the idea of an industry job but because there are so many options I can't imagine choosing any particular field or job right now.

What research are you currently working on?

Currently I am working at the Advanced Particle Detector Laboratory under Dr. Akchurin, Dr. Whitbeck and Dr. Undleeb. At the Advanced Particle Detector Laboratory (APDL), we manufacture environmentally sensitive equipment that require careful monitoring. Since this is a specialized and individual task - it is expensive, and care should be taken such as to not damage the equipment. To alleviate this problem, we are creating a network of Raspberry Pi's embedded with BME280 sensors, to build a modular weather station to monitor the environment conditions in multiple areas around the lab. The 12 "worker" raspberry pi's record temperature, pressure, and humidity data and transmit the data to a localized "hub" pi that reports the data to a "broker" which in turn files it into a database with the intention of establishing a "Weather Stations Dashboard" that would host plots of such environmental data in real time to be readily accessible by all lab members.

What have you enjoyed about your time at Tech? Do you have any favorite classes?

So far my favorite class has been Mathematical Methods in Physical Sciences II because of the fancy math we get to do!

One of the best times I've had at Tech was attending the welcome event hosted by the Physics Department. It's a great way to meet everyone and get familiar with the department as a whole. (Plus there's usually food!)

Do you have any advice for other physics students?

We get so caught up in the moment sometimes we forget that what we are doing here, right now shapes our future. Sometimes all you need to do is take a step back and look at the bigger picture. It is important to recognize that a grade doesn't define you as a physicist but what you know, how you work, and who you are.

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