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Alternative Architectures: An Assessment of the Development Potential of Biological Computers and Quantum Computers

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Abstract. Computers as we know them—with silicon superconductors and linear computing algorithms—are fast approaching their theoretical and practical limits. In the last thirty years, advances have been largely limited to the same underlying ideas of circuitry, just packing more transistors in smaller space. Transistors cannot get much smaller without losing control at a quantum level of the electrons that compose the binary current system, which transistor-based computers have depended on since their inception. To overcome these limits, a new disruptive technology is needed, one that complete reconceptualizes the algorithms of how we calculate problems in order to get around the limits of electronic calculation. Two possible solutions are in development: biological computers and quantic computers.

Although both biological and quantic approaches are currently at the theoretical stage or in proof-of-concept prototyping, researchers believe that at their full potential, both approaches could surpass even the most powerful classic supercomputers in calculating speed and the range of solvable algorithms. Biological computers may also solve certain challenges the world faces regarding compact data storage and energy consumption of transistor-based electronic computers. In order to evaluate these claims, this article begins with an overview of the evolution of computers and the main paradigms used for building computing machineries from early attempts to the present day. From this vantage point, it explores how biological or quantum architecture could translate these traditional concepts of calculation, data storage, and algorithmic thinking in a new physical medium. It reviews the state of the current research and offers an assessment on the potential of the new technology and the obstacles that would need to be resolved to permit its widespread implementation.

Key words: biological computing, quantum computing, computer architecture

Introduction

What does the future hold for the evolution of computer architecture? The first electronic computers occupied large rooms with vacuum tubes, cost hundreds of thousands of dollars (equivalent to present-day millions), and needed a team of personnel to operate (Levy, 2013). Over time, the development of transistors and superconductors, as well as the decreasing costs of producing electronic components revolutionized the manufacture of computers—ordinary consumers can now buy powerful computing devices that fit in a hand. More recently, the explosion of Internet use and cloud computing triggered another computing revolution, completely changing the way people communicate, socialize, and access information within in a single generation.

A world addicted to streaming technology for entertainment and dependent on “Big Data” analysis for market competitiveness has brought forth an exponential increase in the demand for computer resources, yet increases in processing power and storage capacity are not keeping pace. Most processor power advancements in the 21st century were achieved only by connecting more processors or cores to work together in parallel, but increases of power per processor have plateaued. The technology is fast approaching the physical limits of the classic transistor-based architecture. Anticipating this barrier, researchers have begun to look beyond integrated-circuit processors and large data centres to search for alternative architectures. Two directions have seemed especially promising recently: biological computing and quantum computing.

To assess the viability of these alternative architectures, this article first reviews the evolution of computers and the main paradigms that have been used over time to build computing machines, so that we can operate on as broad of a definition of “computer” as possible when exploring what is essential and what can be discarded when considering new architectures outside of the classic transistor-based model. After identifying the key functions necessary, the article then explores how biological or quantum architecture could translate these key concepts, such as calculation, data storage, and algorithmic thinking, to a different physical medium. It reviews the state of the current research and offers an assessment on the new technology’s potential and the obstacles that would need to be resolved to permit its widespread implementation. We conclude that, to meet future demands in computing power and storage, the present situation calls for more than piecemeal improvements based on the old transistor model; it needs a new architecture with new limits—something in the order of vacuum tubes being replaced by transistors or the birth of networked computing. Quantum computers and biological computers could answer this call.

Let’s revisit the question: What is a computer?

Before we can dream about what types of exotic computers could exist in the future, we should first establish what we are referring to when we talk about “computers”. What does it mean to be a “computer”? For an ordinary person speaking of computers in everyday conversation, he or she probably thinks of an electronic device with a screen and a keyboard (whether a physical keyboard or an on-screen one), which has the capacity to run some useful programs. Once we begin to expand the concept of a “computer” to include other objects, however—perhaps a smartwatch, a car, or a washing machine—the confusion begins. If we were to speak of biological cells as components of a computer to the average person, it would be a bridge too far.

Nevertheless, if we want to think creatively about what computers could become in the future, we need a generalized-enough definition and conceptualization to cover new architectures of computers that are unchained from the presumptions specific to the old architecture. Boiled down to its essence, a computer is a system with the capacity to receive data inputs, to execute a set of instructions that represent an algorithm, and to communicate the resulting outputs in an intelligible fashion. (Goni-Moreno & Nikel, 2019). Most computers today implement this process through Von Neumann architecture, consisting of an arithmetic and logic unit, a control unit, memory, and devices to communicate inputs and outputs (Godfrey & Hendry, 1993). In transistor-based electronic computers, the arithmetic and logic unit operates by use of transistors (electronic components that are capable of logging binary states—on or off, 1 or 0) arranged in logic gates. For example, in Figure 1, a series of logic gates stops the current if both switches are on or both are off, which corresponds to the results of binary addition (0+0=0, 0+1 or 1+0 = 1, 1+1 = 10 with a wire that “carries the 1” for the next place value by carrying the current to the next bit’s logic gate).

Modern processors fit billions of such transistors arranged in circuits according to specifications to execute a limited number of predefined operations. Processors are connected to buses that transport information from one address to another: pathways by which inputs from an external device or stored in memory can be communicated as electrical signals arranged in binary code to the processor and outputs can be communicated back, with each location (RAM, hard drives, etc.) having its own address, also reducible into binary code.

The processor, upon receiving these inputs, executes operations in a particular order under specific logical conditions. These groupings of instructions, arranged in ever larger groupings, then become the high-level programming languages from which one can create software. Programmers code using high-level language what should happen to the inputs received from devices or from memory addresses, compilers and interpreters reduce them to machine code, turning instructions intelligible to humans into instructions intelligible to the processor, and the outputs generated are translated back into outputs intelligible to humans.

Because the operations hard-coded into the processor are basic and can be generalized to an infinite number of uses, there is no limit to the number of applications and devices that could be devised to work with a processor. Thus, a "computer" is a universal machine that can execute any algorithm that can be defined in these few basic operations; from whatever state it finds itself, it will receive the inputs given by its environment and run operations to transition to another state.

Although many innovations have changed how we use computers and how we share tasks using networks of multiple processors, the underlying architecture of how a processor works has not changed much since the invention of the transistor. Processors still depend on silicon transistors, and performance improvements to date have been largely thanks to the increased miniaturization of these transistors and multiplication of the number of transistors per microprocessor. This technology is fast approaching the limit of the maximum density to which one can crowd transistors into a microchip, however. Transistors have already reached the size of 2 nm, and a silicon atom is only 0,2 nm. A logic gate requires the ability to stop or permit an electrical current, and once it reaches the size of about ten atoms, it becomes much more difficult to control the current with precision, because electrons can escape the logic gate through quantum tunnelling. (Loeffler, 2022). Without a stable way to control the current, the gates required to perform binary arithmetic no longer function.

Not only are we close to the limit of processing power, but we are also reaching the limits of a different kind: sustainable energy usage. The greater the density of transistors packed into a processor, the greater the problem of overheating and the necessity to expend energy for cooling. Not only that, the rise of Cloud computing has also resulted in the spread of data centres full of server racks, exabytes of storage, and cooling units. At the same time, the demand for storage is increasing exponentially faster than the supply, foreshadowing two problems. The first is ecologic: at some point, the world will reach energy consumption levels that burden the world's current capacity for producing energy. Data centres already consume 1% of the world's energy—a handful of companies consume more than entire countries. (Rooks, 2022). Either the consumption of energy will have to be done in a sustainable way (something that companies such as Google are already trying to address by investing in generating their own energy in order to become climate-neutral), or the world will need to develop alternative directions for computing outside of the electronics-based model. The second is economic: if consumer demand outstrips what the industry can supply in electronic form, companies might need to consider ways to offload some forms of data in other forms of storage.

Although electronic architecture will not become outdated anytime soon, researchers and companies have realized that there will be a need for a radical change at some point and have already started investing in prototypes of new architectures that are not based on electronics. The sections that follow will evaluate two of the more promising directions of study: biological computers and quantum computers.

Biological computers

Biological computers have the potential to outperform transistor-based electronic computers and to address the problem of energy consumption and the storage of zettabytes of data. Theoretically speaking, biological computers have the capacity to fulfil all the requirements of a Von Neumann computer: an arithmetic and logic unit, a control unit, a memory bank, means of input and output, and buses where the different components can communicate data. Each component in the current electronic architecture has a biological equivalent that can fulfil the same function in a biological computer.

Arithmetic and Logic Unit

There are two main approaches to recreating the components of a computer in a biological context: genetic computing and metabolic computing. In genetic computing, researchers repurpose the gene expression process to engineer a kind of biological Boolean logic gate. Cells with the same DNA can function very differently depending on what part of the genetic code is transcribed (i.e., "expressed") to create strands of RNA. Based on the sequence of nucleotides present in the RNA, ribosomes translate this RNA sequence into corresponding sequences of amino acids, which become proteins. Different parts of the genetic code will manufacture different proteins, each of which will affect the behaviour of the cell in different ways. What part of the DNA will be transcribed into RNA depends on the transcription factors present (i.e., the specialized proteins that bind to certain parts of the DNA sequence to enhance, reduce, or inhibit their transcription). Using such transcription factors, experimenters can effectively control the activity of the RNA polymerase (i.e., the protein that transcribes parts of the DNA into RNA strands) along the DNA, creating a kind of biological Boolean gate (e.g., OR, AND, NAND). (Myers, 2013).

By contrast, metabolic computing manipulates metabolic pathways to start and stop the production of certain molecules as a way of signalling "on" or "off" states. So far, metabolic computing experimentation has been limited to certain well-studied strains of bacteria whose metabolism has been engineered to react to different inputs with the output of different metabolic products, and current research focuses on developing a few "metabolic units" to become the building blocks of the simplest low-level code, from which at some point a higher-level language could be constructed. (Goni-Moreno & Nikel, 2019). Even at these formative stages, however, scientists are already exploring ways in which the pathways of metabolic computing can be connected to the outputs from genetic computing (the proteins that are produced from gene expression), to make one larger system and more complicated biological circuitry that can give feedback. For example, the metabolites produced from a metabolic process could, in turn, affect the genetic expression involved in the genetic computing component by binding to a transcription factor and thus affect the promoters and inhibitors in the DNA sequences. (Santhust, Saurabh, & Sanjay, 2018).

These are just two of several experimental approaches under exploration (Moe-Behrens, 2013). Because the technology is nascent, there is not yet a consensus or a standardized approach to creating biological logic gates.

Control unit

Just as electronic computers have a control unit that coordinates the flow of data—in what order and from where to obtain data and instructions—biological computers also need a control unit to coordinate when, where and at what sequence the various instructions need to run. Current efforts have focused on trying to emulate the fetch-decode-execute instruction cycle of a CPU in biological processes. A typical control unit sequence for subtraction would involve the control unit (1) fetching the subtraction instruction from the memory address in the program counter and decoding it into the instruction register at time t0, (2) reading into the program counter the address following the subtraction instruction at time t1, (3) fetching the operand to the subtraction from memory into the register at time t2, (4) preparing the operand in the register and the accumulator (a register in the arithmetic and logic unit that stores the minuend and eventually the result) for subtraction at time t3, and (5) triggering the arithmetic and logic unit to execute the subtraction by subtracting the value in the register from the minuend in the accumulator and saving the difference as the new value in the accumulator at time t4. (Lin, Kuo, & Li, 2018). Finding biological equivalents for each step of the control unit's process requires many lines of research to work in tandem.

For example, the system clock is one important auxiliary component that helps a control unit synchronize activities of the memory banks, CPU operations, the input/output devices, and other components of the computer. Researchers have discovered that the analogue sinusoidal functions of genetic oscillators approximate well the on/off voltage jumps of digital electronic clocks. Such oscillators function by employing several genetic buffers in series (for example, three repressor genes which repress each other in a closed loop) that cyclically change the threshold levels of the buffer to create an oscillation with high and low levels of signal. (Chuang & Lin, 2014). These genetic clocks release with each cycle the by-products that trigger the biological control units to transfer input data to output data at the edge of a clock signal's transition (the biological equivalent of D-type flip-flop circuitry), synchronizing how the control unit carries out instructions in each cycle, just as electronic clocks do. This carefully engineered dance of genetic clock cycles, which triggers a state of high or low concentration of certain proteins as inputs, which activates the RNA polymerase for gene expression of certain parts of the DNA sequence, which in turn produces proteins that trigger other transcriptions, that in their finality produce proteins that represent "outputs", effectively translates to a biological equivalent of what electronic control units do when fetching inputs, decoding instructions, executing operations, and storing outputs.

Parallel computing in biological CPUs

At this point, the observant reader might note that the cycles of genetic clocks seem rather long (in the order of milliseconds or seconds or, even worse, days) when compared to the gigahertz cycles of electronic processors. If protein synthesis and metabolism, by their very nature, are such slow processes, what would be the advantage of this alternative architecture? Aside from the potential energy efficiency advantages in using chemical energy instead of electrical current or having programmable cells that operate with microscopic precision (perhaps one day even eliminating cancer cells), biological architecture creates new possibilities of parallel computing that lie outside of the linearity of the traditional Von Neumann model. While electronic computing may always arrive more quickly at solutions employing linear algorithms, biological computing may excel at algorithms that take advantage of multiple calculations that solve localized problems or other types of algorithms more suited to parallel computing.

To appreciate the types of problems that parallel computing could solve, consider the concept of a "non-deterministic universal Turing machine", which, in contrast to a deterministic Turing machine, allows for multiple transitions from a given starting state to various end states. Algorithms that function on such an architecture could make parallel computations, processing several different transition states at the same time until it converges on a result or output, outpacing linear computation models that go through the various permutations of states one after another until it arrives at the same result. Biological computers are ideal for parallel computing's simultaneity and divide-and-conquer approach. For example, many "copies" of the "program" encoded in a part of the DNA could run at the same time by the proteins its transcription creates, and multiple proteins could execute in parallel some part of the algorithm to arrive at a solution, theoretically at a speed faster than the fastest transistor-based electronic computer or a quantum computer, by virtue of the sheer number of simultaneous threads of execution at play. One source even supposes that a desktop DNA computer could plausibly execute about 1020 operations a second (over 10 times faster than the fastest supercomputer at the time of publication), using memory with an information density of 1 bit per nm3 (about 108 more dense than current memory). (Currin, et al., 2017).

As a prototype of biological parallel computation, researchers in Sweden developed a mechanism which uses the protein myosin (the same protein used in muscles) as molecular motors that apply an algorithm hard-coded into their behaviour to “travel” along canals toward destinations that represent a desired solution. These myosin proteins transform chemical energy into mechanical energy to guide attached filaments of protein through artificially created nanometric canals, which are designed in a way analogous to electronic computer circuits. At each intersection in the lattice of canals, the circuitry implements some logic rules that function as traffic rules for the moving proteins, sorting them just like integrated circuits would implement decision trees that direct the current toward a particular state and ultimately arrives at a desired output to the system. (Nicolau, et al., 2016). In contrast to electronic circuit processors, which can only execute a single operation per clock tick, this biological system can conduct several operations at the same time (based on the number of filaments that are travelling down the network at the same time). Just as nondeterministic Turing machines can start from one state and move to multiple states, the split junctions in the lattice divert 50% of the travelling proteins to go down different canals at each juncture, leading to the parallel discovery of multiple possible solutions.

Biological computers have a big advantage in that that they can create circuits that do not depend on the serial processing of data. An electronic multiprocessor system, even if it were to have multithreading possibilities or several cores, would only be capable of a single operation per clock tick per core. The idea that a processor can do more tasks by multithreading is illusory because while it waits for the data to complete an instructed task, it puts this task on hold to work on another task. By contrast, biological computing could have more agents executing the algorithm at the same time, offering parallel computing in the true sense. If one were to apply this concept to larger problems, it would be possible to have much smaller biological computers that are much more powerful than today’s fastest transistor-based electronic computers and cheaper than quantum computers.

Memory and means of input/output

Biological computers can have their own equivalents of ephemeral and permanent memory. Various proteins’ concentration levels at different stages of execution of a biological CPU task can function analogously to data stored in CPU registers or RAM, while the DNA sequences in the cell that contain the segments that trigger the execution of various instructions have an analogous function to the microcode or the instruction set architecture hard-coded into processor hardware. DNA can last a long time (Callaway, 2021), and cells can replicate and pass on DNA over multiple generations (and control for mutations or errors). One could even imagine a self-regulating cell culture that corrects deviations, much as blockchain technology might correct errors introduced into a ledger by consensus mechanisms which would require unauthorized deviation to infect a large part of the chain before it can change the officially accepted version.

However, researchers are still in the early stages of conceptualizing and testing out possible biological equivalents of ROM, where the data is neither ephemeral such as register and RAM states, nor hard-coded and unchangeable such as microcode imprinted into the processor. Users need a way to save data for the long term but be able to modify it easily and quickly, as electronic computers do when saving and retrieving files from hard drives. However, DNA synthesis, whether from scratch codon by codon or by modifying existing DNA in bacteria through CRISPR, is currently an extremely costly and slow process (often taking days until the bacteria begin to show the desired effect).

One recent article from 2023 offers a different approach: write bits of information directly in existing DNA in a few minutes or hours by using recombinase enzymes that directly store their response to certain stimuli into the DNA sequence. In the specific example explored in the article, researchers employed optogenetic circuits: the stimulation of a light-sensitive recombinase system that responds to the presence and absence of blue light and red light and records its response into the bacteria's DNA sequence via site-specific DNA editing. (Lim, Yeoh, Kunartama, Yew, & Poh, 2023). Using these properties, researchers were able to use bacteria with light-sensitive recombinase to make biological "snapshots", in which light exposure has a similar effect on a bacteria's DNA sequence as light exposure does on a strip of film in analogue photography. Bacterial cultures with light-sensitive recombinase are arranged spatially in different wells (effectively serving as "pixels"), and the bacteria of each well has different "barcoding" data in its DNA, such that these markers leave a long-term DNA record of which spatial coordinates were exposed to light. Later, if one wishes to "read" the stored data for each pixel, they can consider the ratio of how many bacteria samples with a particular barcode contain a DNA sequence indicating exposure to light versus how many samples with the same barcode lack a DNA sequence indicating exposure to light. This method of long-term information storage resulted in a high level of accuracy, with all 96 wells or pixels faithfully reproduced in most conditions, including dilution, drying and reconstituting the DNA, ultraviolet radiation, and freezing.

From a time and financial cost perspective, this new method of using enzymes to react flexibly to real-time stimulus is very promising. However, most research up to this point has been based on a slower technique of storing data that involves methodically splicing the gene sequence of existing bacteria using CRISPR (Jinek, et al., 2012) or by creating gene sequences de novo by assembling DNA fragments and putting together nucleotides (Kosuri & Church, 2014). The CRISPR method developed out of the observation that bacteria have defence mechanisms where they incorporate genetic fragments of invading viruses into their own DNA so that when this part of the bacteria's DNA sequence is transcribed into RNA, this RNA will bind to the invading viruses and render them ineffectual (this immune response itself is called CRISPR). (Jinek, et al., 2012). Scientists found that the splicing of the invading DNA into the bacterial gene sequence always happened at the point in the sequence where an enzyme called Cas9 was bound to the part of the DNA. They realized that, by manipulating Cas9 to cut the DNA sequence where they wished and flooding the environment with a concentration of template DNA fragments ("pooled oligonucleotides") of their choosing, they could induce the bacteria to repair its DNA sequence at the location of the cut using the carefully chosen template fragments as the model. (Shipman, Nivala, Macklis, & Church, 2017).

This method has proven to be useful in precise genetic engineering and has enabled high-fidelity storage of sequences of encoded data. For example, in one series of experiments, researchers encoded the pixel data of an image of a hand and designed a sequence of nucleotides to correspond to this encoded data. This nucleotide sequence was introduced into bacteria using CRISPR, and after a day, the bacteria was harvested to extract the parts of the sequence pertaining to the encoded data. The percentage of introduced DNA fragments that were accurately recalled increased with the quantity of oligonucleotides supplied and the passage of time. When a large number of bacteria were sampled, the recalled image approached 100%. As the results show, bacteria began to demonstrate a high rate of adoption of the introduced gene sequence only after several hours had passed. (Shipman, Nivala, Macklis, & Church, 2017).

The second common approach to storing data using gene sequencing, de novo DNA synthesis, takes even longer than CRISPR. However, the technique is especially useful when one must put together an entirely new sequence of nucleotides for storage purposes that has no resemblance to anything already in nature. (Kosuri & Church, 2014). For example, when creating a very specific sequence of nucleotides for experimentation purposes, there is a need to "write" DNA from scratch. The methods created for experimentation can be repurposed to write encoded data for long-term storage. For example, one could encode an alphanumeric string of data with basic punctuation into a DNA sequence by using an encoding where each permutation of a three-nucleotide codon represents a different letter of the alphabet. The desired message could then be constructed piece by piece into fragments of DNA to be multiplied using a polymerase chain reaction and read later using already well-developed gene analysis techniques.

Biological storage in DNA sequences has some advantages. Electronic storage tends to become obsolete rather quickly, with each generation embracing a new form of storage, from floppy disks to DVDs to Cloud storage in data centres. Physical storage tends to deteriorate, as in the case of historically significant films lost to time because the decades-old film strips containing the images were corrupted by the elements before they could be converted into digital form. The basic read-write operations used in DNA technology, however, will remain in the human toolbox for as long as people have an interest in analysing their own DNA, and DNA as a medium itself can be readable even after millions of years. (Callaway, 2021).

Moreover, DNA storage is extremely compact when compared to the large area necessary to maintain data centres full of racks of servers. A single gram of DNA can store 215 petabytes of data. (Erlich & Zielinski, 2017). The total storage capacity of the world stood at 6.7 zettabytes in 2020 and was projected to grow at 19.2% annually (Taylor, Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2020, with forecasts from 2021 to 2025 (in zettabytes), 2023). That means that, if the current world storage capacity is around 11.4 zettabytes (1.14 x 107 petabytes), then the world's entire current storage capacity could be stored in just 53 kilograms of DNA. The amount of data that was estimated to be stored just in data centres in 2021 could fit in less than 7 kilograms of DNA. (Taylor, Amount of data actually stored in data centers worldwide from 2015 to 2021 (in exabytes), 2022).

Furthermore, electronic data centres' consumption of energy rivals the consumption rate of major countries. (Rooks, 2022). Because DNA storage does not require the large amounts of energy consumption necessary to maintain large warehouses of servers, offloading some of the electronically stored data into DNA archives could have significant impact on the rate of global energy consumption.

Nevertheless, there are obstacles that still need to be resolved before biological storage can become practical. The sort of letter-by-letter encoding and decoding of data described above is extremely expensive and slow compared to electronic storage alternatives. The addition of each codon to a DNA fragment represents a process much more complex than just turning on or off an electrical switch to activate an electronic bit. It involves careful planning of reagents and selection of appropriate biological pathways through which nucleotides can be induced to bind to the correct place in the gene sequence. To address the complexity of this task, the synthetic biology research community has started to pool their common knowledge to build a library of techniques for synthesizing various combinations of gene sequences, and they have begun to create commercial software to add a layer of abstraction to the design process. For example, programs such as Benchling Bioprocess imports from databases of biological components and known properties and has simplified the recipe design process of creating genetic circuits with drag-and-drop interfaces and the universal diagramming of these steps in Synthetic Biology Open Language (SBOL). (Benchling, n.d.). Programs such as Geneious Prime import existing databases of primers to help researchers select the appropriate primers for the task of binding a sequence to a particular location and do automatic debugging to check if the selected primers would bind to unintended locations. (Geneious, n.d.). Just as higher level languages obviated the need for average programmers to delve into assembly language, or just as drag-and-drop Wordpress interfaces allowed for an ease of design without delving into HTML and CSS, the added abstraction to the genetic sequencing process allows for technicians and researchers to simplify the process of designing a procedure for synthesizing a particular sequence of nucleotides.

These procedures do not come cheap, however. In addition to the recipe design costs, the encoding process would require an actual laboratory with a machine capable of assembling the nucleotides according to the procedures specified. In 2023, the synthesis cost per base pair of nucleotides was around \$0.07, meaning that for 1,000 base pairs, with all additional synthesis and handling costs included, was about \$35,000. Each base pair can have four states (representing the four DNA nucleotides), meaning that it can represent two bits. That means this price tag represents the encoding of just 25 bytes of data. The turnaround time for storing this amount of data, according to one vendor's website, is two business days. (Bioscience, n.d.). Because the addition of each nucleotide base pair takes tens of seconds, the encoding of a videoclip of several megabytes took over a month to encode using this sort of process. (ETCenterVideos, 2019). Once sequenced, however, the cost of making copies of already existent DNA fragments using a polymerase chain reaction is extremely small, which means that making backups costs next to nothing.

To streamline the process of writing data, an American company, CATALOG, has been developing a new method in which, instead of putting together a sequence, nucleotide by nucleotide, the company maintains a catalogue of hundreds of short sequences (of about 10 nucleotides in length) with biological "hooks" on either end that are easy to detect and about 100 nucleotides in length, by which these fragments can be linked together in predetermined ways. These sequences are then assembled, not one after another as in traditional linear genetic sequencing, but in parallel. Different fragments of the whole gene sequence are constructed simultaneously, using a technology similar to that in Inkjet printers to deliver specific pre-made fragments to specific substrates. At the final step, various fragments are linked together to make the finalized version of the genetic sequence. The process can handle 500,000 reactions per second, encoding at a rate of 12 MB per second. Initial tests demonstrated that this "printer" can encode entire contents of English-language Wikipedia in 16 hours. (ETCenterVideos, 2019).

Finally, the cost of reading data stored in DNA sequences (outputs) is also high. Although the cost of reading DNA sequences is cheaper than writing them through gene synthesis, there is no real comparison to be had compared to instantaneous reading of data from electronic storage and the affixing of the digital data on a graphical interface on a screen in the matter of milliseconds. Even if these sequences were analysed and decoded to be understandable to a human being, it require yet another process of encoding back into a biological form to communicate to the biological computer again. There are no clear biological analogues to what could function as a data bus to transmit data from input devices or to output devices in a streamlined and standardized way.

All of this seems to point to two conclusions. First, the biological medium may not be the best solution for all algorithms or all storage needs. For example, given the high initial costs but low maintenance costs of biological storage, biological storage may be ideal for archiving documents important to humanity and requiring long-term fidelity but not needing frequent access (e.g., a time capsule of culturally important recordings and documents, an encyclopaedia of how to rebuild civilization in the event of a catastrophe). Similarly, given the low speed at which biological CPUs execute each cycle of operations but the high potential for parallel computing, one might do well to leave linear algorithms to electronic computers and to design algorithms designed to run in parallel (e.g., combinatoric algorithms or divide-and-conquer algorithms) to run on biological computers. For example, a biological search algorithm might be more efficient than a binary search algorithm, in that several biological search "agents" could traverse the data encoded in DNA in multiple simultaneously running iterations and be programmed to naturally attract to a certain location in the DNA to bind to the found result and to produce a by-product signalling if the desired sequence was found and where it was found. A biological computer, equipped with the "peripheral devices" available to bacteria, could be programmed to seek and destroy cancer cells or other bacteria.

Secondly, there appears to be a need for a greater level of standardization and abstraction in biological programming. For example, if programmers think of data as literal translations of electronic binary code to nucleotide sequences and programming languages as literal translations of the operations coded in electronic circuit logic, then every time there needs to be an input or an output or the execution of certain operations in a biological computer, a technician would have to design a way to generate a particular gene sequence and to introduce it into the DNA fragments or the bacteria in play. However, taking as an example the case of the light-sensitive enzymes that, by their natural properties, were induced to record their exposure to light into the DNA sequence of an existing bacteria, a much quicker and more streamlined approach might be to develop biological agents that construct the desired DNA sequences in response to certain stimuli, cutting out the need of expensive gene printers or other brute-force inputs. Similarly, if genetic programmers can design genetic circuits that emulate the basic building blocks of low-level programming code, perhaps one would only need to devise ways to trigger these functions, stringing them together procedurally to create larger functions that complete complex tasks. If there were already bacteria programmed with these basic building blocks and circuit components, genetic programmers would not need to do the equivalent of designing a microprocessor logic, inventing an assembly language, and connecting it sequentially to a higher-level procedural language every time it designs a new strain of bacteria to complete a task of just a few operations.

Given the differing sets of advantages available to biological computing and to electronic computing, the future of biological computing will probably involve hybridization of computing models, in which electronic components capable of electronic computing will calculate outputs for types of tasks it excels at, and electronic-biologic interfaces will hand off exchanges of inputs and outputs to allow biological computers to handle the type of parallel calculations it excels at.

Quantum computers

Ever since physicist Richard Feynman raised the possibility of quantum computers in the 1980s (Preskill, 2021), researchers have placed their hopes on the possibility that quantum mechanics could provide a way of computing at much greater speeds than what is possible through transistor-based electronic computers. Although quantum computers consume much energy and need near-perfect conditions in order to function, they offer a promising model by which one can arrive at solutions faster, not because it can do more operations per second but because it can solve problems while doing fewer operations. For example, suppose we wanted to look for an element in a collection of unsorted data. A quantum computer could find the element in $O(\sqrt{n})$ while an electronic computer performing a sequential search would find the element in $O(n)$. How is this possible?

Computers in the classic sense, regardless of how many computations it could be pushed to do in a second, will always use the same algorithm, which means that solutions will always take $O(n)$ time. By contrast, quantum computers can execute other types of algorithms thanks to its different architecture.

How does a quantum computer work?

The architecture of quantum computers differs even from the bit level. In a computer with transistor-based circuitry, transistors are deemed to have a state of 1 (on) or 0 (off) based on whether the state of the transistor allows the flow of current or not. These bits become the basis by which addresses of memory, data, and instructions are stored. Analogously, a quantum computer is composed of qubits. In theory, any quantum particle capable of two states can be used as a "qubit", but most quantum computers have taken the approach of using electron spin as the qubit. (Loss & DiVicenzo, 1998). Applying formulas of quantum mechanics, one can determine that electron spin has one of two values: +1/2 for "up" spin and -1/2 for "down" spin. (We can arbitrarily assign these two states to the label State 0 and State 1, however, for analogy purposes). Because there are two states, all that we know about logic gates and Boolean mathematics can still apply to quantum computing.

However, there are some important differences that give quantum computing a great advantage in computing efficiency. After one detects the spin of an electron, it will appear as though only one of the two possible values is currently true (either State 0 or State 1). However, before the moment of observation, electron spin exists simultaneously in both states as a “probability”, according to the principles of quantum mechanics. In other words, a bit can only be in one state—100% on or 100% off—while a qubit spin can simultaneously be in both states (for example, 20% State 0 and 80% State 1) until it is measured. The act of measuring and determining a specific state transitions the phenomenon from being in a probabilistic state describable by quantum mechanics to a deterministic state describable by classical mechanics—a transition called “decoherence”. The state of being in multiple possible state simultaneously is called “superposition”. (Vogel, 2017). This property is key to making parallel computing possible on quantum computers, and quantum algorithms that take advantage of parallel computing is what makes quantum computers potentially much faster than linear transistor-based computers.

To explain further what is happening mathematically, consider a quantum state where one qubit exists in this in-between state of superposition—a probability of being in State 0 and another probability of being in State 1 (with the total probability = 1 = 100%). This is often expressed in Dirac notation as follows: $|\psi\rangle = a|0\rangle + b|1\rangle$, where ψ is a name for whatever quantum state we are talking about, the $|0\rangle$ represents the vector $\begin{pmatrix}1\\0\end{pmatrix}$ (where we have arbitrarily assigned being in State 0 to be the element on top) and $|1\rangle$ represents the vector $\begin{pmatrix}0\\1\end{pmatrix}$(where we have assigned being in State 1 to be the element on the bottom, and a and b are parameters that represent the square root of the probability it will be in either state. In other words, the quantum state $|\psi\rangle$ is expressed as a linear combination of the different “classic” states that it could be in (State 0 or State 1) multiplied by parameters that show the weight of probability for each state.

For example, one common quantum state that is often discussed in connection to qubits is called $|+\rangle$ by convention, and is defined:

$$|+\rangle = 1/\sqrt{2}\ |0\rangle + 1/\sqrt{2}|1\rangle = 1/\sqrt{2}\ \begin{pmatrix}1\\0\end{pmatrix}+1/\sqrt{2}\ \begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}1/\sqrt{2}\\1/\sqrt{2}\end{pmatrix}$$

Taking the resulting vector and squaring each element, we arrive at the probability vector

$$P(v) = \begin{pmatrix}1/2\\1/2\end{pmatrix}$$

This shows that for this quantum state named $|+\rangle$, there is a 50% chance that the electron is in State 0, and a 50% chance that the electron is in State 1.

To visualise the idea of superposition and the probabilities from the equations in Figure 16, we can look to Figure 17, which helps draw a visual analogy of the in-between “superposed” state before decoherence. The blue sphere represents all of the superposed states possible, where the diagonal vectors ψ

that are a linear combination with parameters a and b represent superposed states. The extreme 100% up or 100% down state after decoherence (which is analogous to what we are used to when we think of 0 and 1 of ordinary bits from electronics) is represented by the North and South poles (the orthogonal normal bases |0> and |1>). (Tonello & Grigolini, 2021).

Now that we have the tools to describe a quantum state as a linear combination of classic states and parameters related to probabilities, we could imagine doing some sort of action to change this state. For example, in ordinary transistor-based computing, a circuit can change the state of the current passing through by using a NOT gate. A high input voltage ("on") will cause the current to escape in a different direction due to the activation of a transistor, such that the voltage will be low ("off") at the output location. A low input voltage ("off") will cause the transistor not to activate, such that the current reaches the output location ("on"). (Kuphardt, n.d.) Analogously, we can think of "something" being done to the qubit to also cause a NOT effect of inverting whatever its current state is. Mathematically, we can express what is happening by multiplying the state vector with a matrix that represents the NOT operation (i.e., the Pauli X operation, often known as the "bit-flip" or noted as σx).

$\sigma x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$ … If we multiply |0>, which represents the qubit on State 0, with σx, we get:

$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$

Similarly, multiplying σx with |1> results in |0>. Thus, it is possible in the quantum world to have logic gates (represented by matrix operations that can be done to change the quantum states), but the 0 and 1 no longer represent high or low voltage running through an electric circuit, but rather what state the quantum particle is in. As such, the physical implementation of each "logic gate" involves the careful introduction of microwaves at specific frequencies or the manipulation of external magnetic fields to affect the qubits, and producing the desired results with low error rates is an ongoing field of study. (Bardin, Slichter, & Reilly, 2021). Researchers have already succeeded in creating quantum logic gates, which change the spin of qubits isolated in the small space of a quantum dot by exposing them to targeted photons or electromagnetic fields. For example, in 2015, researchers from Australia and Japan created the first quantum logic gate using particles of silicon-28, in which electrons (used as two qubits) were kept at a distance of 100 nm between each other through electrodes. By manipulating the voltage of the electrodes and targeting microwave pulses, one could change the qubit spin. Because the voltage determines if the qubits have the same spin or not, the spin of entangled qubits will remain dependent on one another until an outside interference decouples them. At the end of the process, after the calculations are executed, the results can be "measured" by beaming a ray of light (photons) at the exact frequency in which atoms in an excited state will remain transparent and atoms in a base state will light up. (Johnston, 2015). Using such techniques, one can engineer a “universal set” of quantum logic gates that are functionally identical to the logic gate circuitry of transistor-based computers by applying a series of operations (physical stimuli in the form of microwaves, lasers, or the like) to have the desired end effect on the qubits.

At this point, one may wonder why one should go through all of the trouble to do calculations through qubits, if the underlying logic gate architecture is the same (only much more costly and harder to control). Looking just at each qubit in isolation as a self-contained system (as we have done up till now) does not capture what makes quantum computing so different. The point of using quantum computing and its very nature as a superposition of states is that this property of being superposed makes possible a very useful phenomenon called quantum entanglement, in which we discover that two or more different probabilities for a state are mathematically inextricably linked to other. In actual observed reality, that has meant that qubits that have become entangled, when measured, will always yield results consistent with the mathematical relationship that defines the correlation between the two particles. The fact that quantum particles exist in multiple states probabilistically and that operations done to entangled particles will produce related results can be exploited to have the effect of doing parallel computing for all possible values of a function, simultaneously. This is why a quantum algorithm specifically designed to run in parallel will solve certain types of problems much more quickly than any classical computer. (Bub, 2007).

This entanglement or interdependency between two qubits (or more) can be induced by performing a series of operations (or exposing the qubits to the physical equivalent of doing these mathematical operations) that result in a compound system that cannot be factorized into separate qubit states. For example, suppose there is a two-qubit quantum state named $\phi+$, where the possible states are for both to be in State 0 (i.e., $|00\rangle$) or both to be in State 1 (i.e., $|11\rangle$). (Here, since there is no mention of $|01\rangle$ or $|10\rangle$, we presume that there is zero probability for having just one of the qubits in State 0 or 1.)

$$|\phi+\rangle = 1/\sqrt{2}\ |00\rangle + 1/\sqrt{2}|11\rangle$$

This system of two qubits is considered “entangled” because it cannot be factorized to be expressed as a tensor product of two individual qubit states $|a\rangle \otimes |b\rangle$ (two separate events a and b). Once a series of operations on two qubits has produced an entanglement, they can be exploited for parallel computing. (IBM, 2022). Some of the most common operations to make two independent qubits entangled is to apply the Controlled NOT (CNOT) gate ($\begin{pmatrix}0&1\\1&0\end{pmatrix}$), which we saw earlier, or the Hadamard gate $1/\sqrt{2}$ ($\begin{pmatrix}1&1\\1&-1\end{pmatrix}$) . For example, applying the Hadamard gate to $|0\rangle$ would result in the following:

$$H|0\rangle = 1/\sqrt{2}\ \left(\begin{pmatrix}1&1\\1&-1\end{pmatrix}\right)\begin{pmatrix}1\\0\end{pmatrix} = 1/\sqrt{2}\ \begin{pmatrix}1\\1\end{pmatrix} = 1/\sqrt{2}\ |0\rangle + 1/\sqrt{2}|1\rangle$$

After performing the operations from the Hadamard matrix, we no longer have an expression just based on |0>, but one that is based on both |0> and |1>, such that these two qubits are dependent on each other (they are not tensor products of two independent states).

As one can observe from Figure 18, each part of the process of preparing and utilizing qubits for quantum calculation has an equivalent in the mathematical representations of quantum states and operations. Individual qubits are entangled through procedures that have the effect of a Hadamard gate or other operation, resulting in an entangled linear combination of qubits, and these qubits can then be induced to perform certain algorithms, with all of the various states being simultaneously affected and making parallel computing across multiple paths possible. From there, other manipulations such as interferences are done so that quantum states that interfere with each other can amplify the probability of the desired results, and finally, a measurement can collapse the probabilities into a certainty (reverting to a classical system of 0% and 100% probabilities).

Advantages and disadvantages of quantum computing

Equipped with a better understanding of how qubit circuits work through probabilities and the use of quantum entanglement, we now turn to the question, “So what?” Practical implementations of quantum computing are still few and far between. Electrons used in qubits need to be stay isolated, encased in a “quantum dot” sphere made of superconductors of silicon and germanium, cooled to almost absolute zero, and kept in place by magnetic fields (Vogel, 2017). This is because a quantic system needs to function without outside interference of any energy waves. For that reason, quantum computers are not yet economically viable in terms of energy consumption and cost. The largest quantum computer so far has 433 qubits, but IBM has already planned to build one with 100,000 qubits in the next ten years (Brooks, 2023). However, researchers and large firms such as Google (Google, n.d.), IBM (Brooks, 2023), Amazon (Carlsten, 2021), and Microsoft (Azure, n.d.) have remained enthusiastic about the potential of quantum computers to outpace classical electronic computers based on transistors.

For now, a quantum computer excels and the solving of a particular class of problems: those that, in themselves, have a quantic character that depends on the modelling of exponentially chaotic or stochastic phenomenon (e.g., prediction of weather, protein combination). For example, traditional electronic computers can find prime factors for a number based on a Euclidean algorithm, but a quantum computer can apply quantum algorithms (e.g., quantum Fourier transformations, Shor’s algorithm) and parallel computing via entangled qubits to arrive at a solution faster than any transistor-based computer. As a point of comparison, IBM calculated two prime factors for x, a number with 250 figures, in about 2,700 core years using a transistor-based computer. (Qisket, 2023) Sycamore, a quantum chip made by Google, was able to arrive at the solution of such problems in just a few minutes, whereas a supercomputer the size of two tennis courts took several days. Some have called this the “Noisy Intermediate-Scale Quantum” era, where quantic computers of around 50 qubits can already solve complex problems that the most powerful supercomputers with traditional architecture cannot. (Preskill, 2021, pp. 7-9).

The development of quantum algorithms and computers could have wide-ranging implications on the cryptography protocols that rely on factoring large numbers. Up till now, many encryption protocols depended on the fact that even the best supercomputers cannot quickly solve the problem of finding prime factors of an extremely large number. Some of these problems would no longer be impossible to do in a short amount of time, thanks to quantum computing. (Anticipating this development, cybersecurity firms are already researching other forms of encryption based on the types of problems that even quantum computing would not be able to solve quickly.) In addition to affecting cybersecurity, quantum computing could also revolutionize how we solve large optimization problems, which require finding solutions to a large system of linear equations (Harrow, Hassidim, & Lloyd, 2009), by providing a tool by that can run efficient quantum algorithms. In statistics as well, faster quantum algorithms have improved upon the classical algorithms for the bread-and-butter of statistical analysis—the least-squares method for linear and multivariate regression—from a best-case outcome of $\Omega(n)$ under classical algorithms to an $O(\log n)$ time complexity (Liu & Zhang, 2017). The ability to process large amounts of data and to apply calculation-heavy statistical methods quickly would redefine the bounds of what is possible in real-time analysis using Big Data. Similarly, such shortcuts could have a significant impact on other data-intensive calculations, such as machine learning and other artificial intelligence algorithms.

However, these types of problems constitute only a small subset of all computable problems and, for the moment, classic transistor-based computers are superior to quantum computers for most tasks because not all algorithms are best suited to a quantum approach. Some experts predict that future computers will probably use a hybrid design in which computers with classic transistor-based architecture delegate certain tasks more suited to quantum algorithms to a quantum processor, much as a classic CPU might delegate certain specialized operations to a GPU (Roberts, 2019). In order to discover more quantum algorithms and encourage more practical applications for quantum computers to handle one day, companies such as IBM have launched many open-source learning platforms and made available many free resources to encourage more computer scientists and programmers to get involved in the development of the technology. Just as programs such as OrCAD helped develop designs for classic processors, integrated development environments (IDEs) and software develop kits (SDKs) such as IBM’s Qiskit (IBM, n.d.), D-Wave’s Leap (D-Wave, n.d.), Google’s Cirq (Google, n.d.), Amazon’s Braket (AWS, n.d.), and Microsoft’s

Azure Quantum (Azure, n.d.) allow anyone to design quantum circuits and for any Python developer to code software using libraries that implement already-discovered quantum algorithms. For the time being, many of these resources are free to students or developers who contribute to software development.

Another advantage of quantum computers is their ability to perform interconnected computations at a distance from one another, without the need for a cable or a wireless connection. After two qubits are coupled by quantum entanglement, they can be separated by long distances (for example, a quantum dot can be transported from Bucharest to Mars, but immediately after the spin of one quantum dot is detected, the other one also collapses into a correlated spin despite being millions of kilometres away). At first, this result may seem unintuitive, but if we think of the mathematics behind the model, as a matrix, we can appreciate that the values of some elements in a system with quantum inseparability would be affected by others, such that the measure of some related elements would require the other elements to take on a particular value to remain consistent with the measured value. Perhaps this sort of dependency could be harnessed to be used in monitorization, cybersecurity, or the sending of pre-agreed-upon distress signals, where the tampering or detection of one quantum parameter could cause the instantaneous decoherence of other parameters and trigger a timely response to a threat.

For the moment, however, practical problems stand in the way of large-scale adoption of the technology. Aside from the limited number of algorithms and development of applications (a problem that would disappear in time with the involvement of more developers), there are significant practicality issues with the hardware. Keeping a qubit in a perfectly isolated and controlled state in almost 273 K consumes a lot of energy. Because conditions need to be maintained so precisely, error rates are relatively high at about 1% per gate (a pair of qubits) and require many error-correction measures. Because qubits are so sensitive to any source of interference, some have proposed that one would need to entangle hundreds of qubits to function as a single qubit in order to build in resistance to interference (Cho, 2020). The most powerful quantum computer to date, however, has only about 433 qubits. Another approach may be to use statistical probability. For example, Google Sycamore uses a strategy in which the qubit gates arrive at a correct response only once per 500 runs, but the operation is repeated millions of times until there is a statistical convergence on a result almost certain to be correct. (Brooks, 2023).

Thus, the technology of quantum computing is the early stages of development, just as biological computing is. It has a conceptual basis and some prototypes in development to show that a quantum processor is possible, but there are a significant number of problems that need to be solved until a quantum computer could become a realistic alternative to classical computers. Even if Cloud computing has created the possibility for anyone to access a quantum computer without having a controlled laboratory in his or her home, the cost of having even one quantum computer to address all of the computing demands of the world is still astronomical. There is not a way to entangle thousands of qubits into a circuit. Even if such hardware were to exist, it would not present an advantage over classical computers for the majority of algorithms, because for now quantum computers perform about the same number of operations per second as a classic computer. Their one advantage in computation comes from the fact that a quantum computer can execute a very specific class of algorithms with greater efficiency: quantum algorithms. There would need to be mathematicians and other experts from each field to design new quantum algorithms, computer scientists and physicists to design the quantum logic gates to execute them, and programmers to implement these algorithms in applications with an interface that is easy to understand for the casual user.

Conclusion

The discussions above only give a general presentation about tendencies that are still in their nascent stages. Just as the researchers worked on ENIAC or ARPANET without smartphones or the modern-day Internet in mind, we are at the beginnings of creating the building blocks to create the technology of tomorrow. We stand at a point opportune in history, in which researchers were able to prove the viability of the concepts proposed, yet there is much to design in practical terms: the design of architectural components of a biological or a quantum processor, the coding of new operating systems and the creation of new algorithms to run on them, and the creation of software that connects computers, devices, and users to allow communication among them.

As noted in the discussion above, both biological computing and quantum computing are specialized tools that are best suited for specialized algorithms. Thus, the best approach for integrating this new technology into practical use would be to look for junctures where this technology could share the calculation load with classic computers, with a general-purpose computer delegating specialized tasks to biological computers or quantum computers. For this to happen, there would need to be development of more forms of technology to connect these different architectures together, such as Cloud computing networks and APIs that offer ordinary computers the ability to connect with quantum computers kept in remote, carefully controlled environments. Furthermore, the biological or subatomic physical processes behind the hardware design research may be complicated, but a greater level of abstraction between the hardware level and the software/algorithmic level may allow for more people with only generalized programming knowledge to take advantage of the new technology. Just as a typical software engineer does not need to know about machine code or chip architecture to create a useful program, there should be some effort to standardize some basic building blocks of low-level operations (for example, some of the more common procedures of gene synthesis, or the engineering of enzymes whose specific task is to modify existing genetic code in real-time) to get to the point where biological computers have the user-responsiveness and the generalization to create a basic “operating system” on which others can build.

It may be too early to expect anything concrete regarding such suggestions, but we can encourage more inquisitive minds to join in the global effort to develop these alternative forms of computing. Because the technologies are still at the beginning stages, there are comparatively few people with the abilities necessary to develop biological and quantum computers. As there is a dearth of qualified computer scientists with these specialties, large companies are actively promoting the technology with free educational platforms and free (or heavily discounted) access to prototype computers in order to reach a critical mass of interested developers. Companies and countries alike have the opportunity to become an early market entrant on the next big industrial leap—a chance to shift the balance of power and the course of history. With the explosion of artificial intelligence and the use of Big Data, those who learn to harness these new forms of parallel computing especially suited to neural networks and simultaneous probability-based calculations will have a definite advantage. This moment presents a rare opportunity to delve into the foundational layers of these technologies, becoming the trailblazers who define the operational landscape of the forthcoming generation of computers. The time to get involved is now.

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Argentina’s economy – past, present and future

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Abstract

Argentina, located in the southern part of South America, has undergone significant economic fluctuations. In the first part of the 20th century, it experienced rapid growth, becoming one of the most prosperous countries due to agriculture. This study focuses on analyzing the economic evolution of Argentina, examining periods of prosperity in the early 20th century, the crises of the 1930s and 1940s that led to instability, as well as new directions under the leadership of President Javier Milei. The research will assess current economic challenges, including high inflation and external debt, as well as government stabilization strategies.

Keywords: economy, Argentina, Javier Milei, inflation.

Introduction

In the research on Argentina's economy, emphasis has been placed on analyzing its economic evolution from the past, present, and future, in the context of the recent elections won by Javier Milei. The objectives of this study are to investigate the impact of economic crises on Argentine society, to identify the mechanisms by which economic policies influence consumer behavior, and to evaluate the economic prospects under the new administration.

The main hypothesis of this research suggests that political decisions in Argentina, both in the past and present, have generated significant negative effects on the country's economy, leading to a deterioration of the economic situation for the entire population, especially for the middle and lower classes, who have faced increasingly severe poverty. The secondary hypothesis states that inflation in Argentina is primarily influenced by internal factors, such as the monetary and fiscal policies adopted by the authorities, but also by external factors, such as global economic trends and changes in international trade.

Between 1800 and 1920, Argentina's economy experienced significant expansion, supported by a prosperous agriculture sector and a robust labor force, fueled by massive immigration from Europe and a favorable legislative framework. By 1885, Argentina had developed an extensive network of over 2,700 railways, approximately 5,000 kilometers in total, which contributed to economic integration and facilitated the transportation of goods. This railway network was essential for connecting agricultural regions with domestic and international markets, thus boosting trade and economic development. During this period, Argentina became one of the main exporters of agricultural products, particularly meat and grains, strengthening its reputation in the global market. Foreign investments increased, and the country began to attract international capital, accelerating the modernization of infrastructure and agricultural industry. This combination of factors contributed to unprecedented economic prosperity, transforming Argentina into an important player on the world stage.

The year 1905 marked the beginning of Argentina's economic decline, caused by a popular uprising against the government at that time. The reforms implemented by the new government, which included severing trade ties with Europe and restricting immigration, were crucial for supporting the economy—led to a sharp decline in GDP of 10%. This economic deterioration had long-lasting effects, contributing to social instability and financial difficulties that continued to affect the country in the following years. Additionally, the decrease in the number of immigrants reduced the available labor force and negatively impacted the agricultural and industrial sectors, exacerbating the economic crisis. Consequently, the drop in GDP and the shrinking labor force created a downward spiral of crisis, with rising unemployment and poverty among the population. Many families faced significant difficulties in securing their daily livelihoods, and social discontent grew. In this context, labor movements and protests demanding economic and social reforms emerged.

The construction of the Panama Canal in 1914 significantly reduced the geopolitical importance of Argentine ports, which had previously played an essential role for ships from the United States stopping for supplies on their journey from the East Coast to the West Coast. This change diminished Argentina's strategic relevance in the context of international trade, contributing to a reconfiguration of the country's global economic and political relations.

The Great Depression of 1930 had a devastating impact on Argentina. Great Britain abandoned imports from the country, turning to other sources, which led to an increase in layoffs among workers. The middle class struggled to meet basic needs, while the wealthy saw their businesses and funds gradually collapse. To prevent Argentina from completely severing ties with Britain, the two countries signed the "Treaty of Trade and Navigation." This treaty allowed for the export of food to Britain in exchange for the import of coal and gasoline, while also being exempt from export laws.

In 1981, Argentina decided to take control of the Falkland Islands, which were then held by Great Britain. They invested considerable sums to ensure a swift conquest of the islands. In response, Great Britain mobilized a fleet of ships, successfully recapturing the Falkland Islands and leaving Argentina with a significant budget deficit.

Currently, Argentina is experiencing inflation of over 100%, being much poorer than in previous years. After the 2023 elections and Javier Milei's victory, the new president promised economic reform and the reduction of unnecessary costs for the country to become prosperous in the future.

Javier Milei made the following decisions: reducing the number of ministries from 18 to 9, proposing to consider the US dollar as the official currency, liberalizing markets by promoting competition and lifting trade restrictions, and attracting foreign capital, simplifying taxes and cutting fees that discouraged investment. Moreover, Argentina withdrew from joining the BRICS economic bloc, scheduled for 2024, making a radical shift in its national policy. The government has turned its attention towards a rapprochement with the United States and European countries, leading to a deterioration of relations with China and Russia. Additionally, a massive privatization process of key state-owned companies began, such as the Argentine railways, the national electricity company, the national bank, and the national mint, among others. At the same time, President Javier Milei declared the intention to integrate Argentina into NATO, marking a new direction in the country's foreign policy.

Other approaches

In the context of the financial crisis, Argentina adopted a new investment strategy, focusing on military conflict. This decision was driven by the attempt to seize the Maldives, which were then under British control. Thus, the graph below was created to illustrate Argentina's economic status:

As can be seen, Argentina experienced significant economic instability, taking on a high risk by investing in this war. At the end of conflict, Argentina suffered greatly economically. Moreover, they failed to conquer the islands because Britain launched a counterattack that destroyed the Argentine army.

As noted, Argentina experienced an explosive increase in the inflation rate in 1983, reaching 344%. This rate stabilized over time, but it significantly impacted the plans for economic reform.

Javier Milei's economic plans for repairing Argentina's economy are very ambitious and radical. To reflect this aspect, the following chart has been created:

This chart illustrates the changes implemented and highlights the difficulties Argentina faces during the transition under Milei's leadership. As noted, Javier Milei's policies have had mixed effects. On the one hand, he has managed to reduce inflation in a short time, but on the other hand, economic growth and the standard of living have suffered due to austerity measures and radical reforms.

One of Javier Milei's proposals to restore the economy is the dollarization of Argentina, which means replacing the peso with the US dollar as the official currency. Among the advantages of dollarization are price stability, reduced currency risk, and increased investor confidence. However, this approach also entails a loss of monetary sovereignty, significant transition costs, and a dependence on US monetary policy, which could limit Argentina's ability to manage internal economic crises.

While politicians like Javier Milei promote dollarization as an urgent solution to combat inflation and stabilize the economy, critics argue that in the long run, it could exacerbate the country's economic vulnerability and intensify social inequalities

Research methodology

To conduct this study on the evolution of Argentina's economy from the past, present, and future forecasts, a survey was distributed on the Google Forms platform to collect data. The interviewees had the opportunity to answer questions without their personal information being collected. The 8 questions focused on annual income, current employment, their opinions on government decisions before and after Javier Milei's candidacy, their knowledge about inflation and the economy in general, and one question asked for their views on the possible effects of dollarizing the economy. Finally, participants were invited to provide suggestions on how the country's economy could be repaired. The data collection period was from September 10, 2024, to October 8, 2024.

During this time, approximately 120 responses were collected from residents of Argentina. Additionally, broader discussions related to this topic took place, contributing to the study.

Research result

After processing the data, it was found that many respondents expressed a high level of confidence in the plans proposed by Javier Milei and are optimistic about the future of Argentina's economy. In response to the question about annual income, approximately 60% of respondents reported that their income is below the national average, indicating a significant portion of the population facing financial difficulties. 30% indicated an average income, while 10% stated that their income is above average.

55% of respondents mentioned that they work in the private sector, while 30% work in the public sector. The remaining 15% indicated that they are either freelancers or unemployed.

Regarding opinions on government decisions made before and after Javier Milei's candidacy, 60% of respondents believed that the economic decisions during the previous period were ineffective, leading to worsening inflation and a decrease in living standards. After Milei's candidacy, 45% of interviewees expressed optimism about the proposed economic reforms, while 35% identified as skeptical or concerned about potential negative effects.

When asked about their economic knowledge, 70% of respondents said they understand the impact of inflation on purchasing power, and 65% expressed concern about the effects of inflation on the national economy. Only 20% acknowledged having limited knowledge of economics but indicated interest in learning more.

When asked about the possible dollarization of Argentina's economy, a highly debated topic in the context of Milei's policies, 55% of respondents expressed support, believing that this measure could stabilize inflation and bring more economic security. However, 35% opposed dollarization, arguing that it could reduce the country’s economic sovereignty.

Regarding suggestions for improving the economy, 40% of participants mentioned the need to reduce corruption and improve government efficiency. Another 30% suggested stimulating foreign investment and developing the local industry, while 20% emphasized the importance of protecting vulnerable groups and increasing wages.

Conclusion

The study of Argentina's economy highlighted both historical difficulties and current challenges, emphasizing the role of political and economic decisions in the country's evolution. After a period of prosperity in the 19th century, supported by agriculture and infrastructure investments, Argentina entered a phase of economic decline due to political instability, decreased immigration, and changes in international trade. These crises severely affected the middle and lower classes, deepening poverty and inequalities.

The election of Javier Milei as president in 2023 brought to the forefront a set of radical economic measures, such as reducing the number of ministries, proposing the dollarization of the economy, and liberalizing markets, all aimed at stabilizing the economy and attracting investment. However, these ambitious reforms have generated concerns among the population, particularly regarding their effects on the most vulnerable.

As these changes are still being implemented, a new study will be necessary in the future to assess the impact of Milei's policies on Argentina's economy. This will provide a clearer perspective on how the proposed economic reforms will affect inflation, the standard of living, and Argentina's role on the international stage.

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Economic perspectives on gender inequalities in the labour market

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Abstract. This article delves into the complex landscape of gender inequalities within the economic sphere, drawing inspiration from the pioneering work of Claudia Goldin, the recipient of the 2023 Nobel Prize in Economics. The article begins by exploring Goldin's groundbreaking research on the history of gender inequality and its showcasing of more complex concepts that highlight the depth of such issues. By analysing the factors influencing occupational choices and career opportunities, the research aims to offer insights into the persistent inequality in earnings between men and women. Furthermore, this article investigates the consequences of gender inequalities on the broader work market. Inspired by Goldin's emphasis on the role of flexibility in working hours, the study examines how rigid workplace structures contribute to the perpetuation of gender-based stigma.

Key words. gender inequality, wage gap, gender gap puzzle

Introduction

Gender inequality not only presents a social issue that has long-lasting negative effects on one specific marginalized group, but an economic problem that stunts growth and development. Gender inequality in the labour market affects everyone to a different extent, yet there is still much apathy and a lack of understanding about its causes and its impact. Because this apathy and passivity contribute to the problem of gender inequality, there needs to be research that clearly communicates how gender inequality affects everyone in society and demonstrates the urgency of taking action towards change and true inclusivity everywhere. If the only voices that fight for equality are those that are not in positions of power and privilege in many parts of the world, the changes will not occur anytime soon. This article seeks to document the evidence of negative impact of gender equality in the labour market and identify ways to take a proactive role in combating gender inequality, pay gaps and the lack of opportunities.

To demonstrate the ongoing existence of this problem and the need for action, the article first offers a historical context of the roots of gender inequality, recent efforts to combat the gender gap, and its persistence today. It then analyses the possible causes of this inequality by evaluating several economic studies done by researchers. After considering the empirical evidence, the article demonstrates that the economic independence of women affects society as a whole by analysing correlations between a country's economic indicators and their gender benchmarks. As evidence, it considers several countries—Yemen, New Zealand, Japan and South Korea—in detail to demonstrate how the status of women can greatly affect the stability and economic prospects of a country. To conclude, it explores the global solutions that have been proposed, including their limitations and potential, and makes suggestions about the way forward.

A brief history of women in the workplace and gender inequality

Studies on economic gender inequality have revealed that diverse and inclusive workplaces for women are not only important to social justice, but also to corporate success, economic efficiency and long-term economic growth. In the last decade, conversations surrounding gender inequality have become more mainstream and gathered global attention through numerous movements and organizations. Over the last few decades, 2023 Nobel Prize laureate in economics Claudia Goldin has conducted groundbreaking research highlighting the importance of gender equality in the labour market, revealing the phenomenon's true complexity. (Nobel Prize Outreach AB, 2023). Her studies have followed the role women have played in our world's economy throughout the centuries and uncovered the key factors that enable inequality and the main sources of the remaining gender gap, such as human capital investments and occupational segregation. (Goldin, 2015).

Research such as Goldin's has uncovered an economic history of the labour market with deep roots in gender inequality. Social, historical and economic factors from centuries past live on to this day, having determined the distribution of power, opportunities and social influence inherited over generations. To begin with, researchers that have argued persuasively that the gender differences may have appeared at first due to cultural practices rather than biological factors, demonstrating through prehistoric archaeological findings that males did not always necessarily appear to have superiority over women. (Cintas-Peña & García Sanjuán, 2019). However, over time, agrarian societies often determined gender roles by physical strength, leading to a division of labour where men were usually entrusted with more physically demanding tasks, while women focused on familial and domestic responsibilities. (Shenk, et al., 2010).

The transition from an agrarian economy to an industrial economy led to changes in working methods and culture. Men moved on to factories, leaving women to manage the household and agriculture. Even as women began to enter the workforce in greater numbers, however, they were often confined to low-paying jobs that would reflect and further impose gender stereotypes. For instance, some of the most common jobs a woman could have during the Industrial Revolution were teaching, nursing or working in textile factories. (Scott & Tilly, 1975).

The World Wars had a great impact on the status of women, as well, with many women participating in the workforce during times of war. Some historians and experts even credit the high level of women's participation in the World War I war effort as one of the catalysts that led to multiple countries extending the right to vote to women after the war: Canada in 1917; Britain, Poland and Germany in 1918; and in Austria and the Netherlands in 1919. (Higgins, 2023). The Second World War was a major impetus behind the significant growth in the number of women in the workforce, but after the war, traditional gender roles were reaffirmed, and women were encouraged to return to their familial duties and rely on their husbands' incomes only. The 1950s and 1960s were defined by the idealisation of the nuclear family, with men as breadwinners and women as housewives. (Corbett, et al., 2023). However, the effects were irreversible: women learned valuable skills while occupying various jobs and remained in the workplace in large numbers (about half remained at work) through the post-war years. (Acemoglu, Autor & Lyle, 2004; Goldin, 1991). Men returning to the workplace, wage inelasticity, and the unwillingness of employers to view male and female workers as perfectly substitutionary led to relatively low demand and high supply of women at work that led to an exacerbation of the income inequality that persists to this day. (Acemoglu, Autor & Lyle, 2004).

These realities brought about the feminist movement that challenged traditional gender norms and advocates arose to demand equal opportunities in all aspects of life, including the labour market. In the 1960s, the United States passed important legislation in order to combat the issue of inequality in the workplace. The

Equal Pay Act of 1963 became the first piece of federal legislation to mandate equal pay for equal work. In 1964, the Civil Rights Act went a step further, banning sex-based discrimination. (Bailey, Helgerman & Stuart, 2022).

Although the 20th century brought about a steady progression of milestones for women advancing in education and entering various professions, it is well known that even in 2023 the gender pay gap persists and women struggle to access leadership positions. The 2023 Global Gender Gap Index results showed that at the current rate of progress, closing the economic participation and opportunity gender gap might take another 169 years and that there is no country in the world to achieve full gender equality yet. (World Economic Forum, 2023). Several factors have garnered researchers' attention as possible causes of gender inequality in the workplace, such as policies for parental leave, childcare and flexible work arrangements. Furthermore, economic gender inequality varies by country and culture, influenced by factors such as legal frameworks, cultural norms and social perceptions and beliefs. The next section eschews an overly simplified approach of relying on any one scapegoat for gender inequality, seeking instead to identify how many different causes begin to impact female participation in educational and career opportunities in the course of a lifetime.

Consistent discrimination over a lifetime: the deep-rooted causes of gender inequality

A central theme in Claudia Goldin's research is the concept of human capital being a crucial factor in the ongoing phenomenon of the gender wage gap. But what exactly is human capital and why is it so important in the discourse about inequality? Human capital is defined in the Oxford English Dictionary as "the skills the labour force possesses and is regarded as a resource or asset." (Oxford English Dictionary, 2023). It encompasses the notion that individuals invest in themselves to boost the quality of their labour, using means such as education, training and health to increase his or her productivity and workplace opportunities. (Goldin, 2016).

When discussing gender inequality, the concept of human capital becomes particularly important as it highlights differences in the investment, development and use of the skills and talents of men and women. First, human capital is often built through education and training. Discrimination in access to education between the sexes can therefore contribute to the issue of inequality. If women have limited access to quality education and training, their ability to have the skills required for higher paying jobs will inevitably be affected. Second, human capital is influenced by work experience. Gender disparities in opportunities for professional growth, promotions and career advancement can prevent women from gaining valuable work experience, impacting their long-term earning potential. It is also of great importance to highlight the fact that human capital extends beyond skills and education to include health. Gender inequality in access to healthcare, maternity leave policies and work-life balance can affect women's overall human capital development, influencing their ability to fully participate in the labour market. (Goldin, 2016).

In short, human capital is an important factor when addressing gender inequality, as it underlines the need for equal opportunities in education, training and career development. Investing in the development and utilisation of the human capital of both men and women not only promotes fairness, but also encourages economic growth and sustainability. Although there have been some efforts to implement affirmative-action hiring policies or to extend sources of funding specially targeted toward women, such policies only attempt to equalize the end result. A more sustainable and systemic solution would balance these end-result interventions with other interventions at all stages of a woman's life to ensure equal access to opportunities to develop her human capital from childhood to career maturity.

A discussion about social standards and concepts that impact gender inequality in the economy must take into account the economics of marriage and family, as these institutions and societal roles have governed women's lives and identities for centuries and continue to have a defining role in many cultures to this day. Traditional gender roles often influence the division of labour within households, with women handling a significantly bigger burden of domestic responsibilities. This dynamic, along with career interruptions related to childbirth and caregiving, contributes to income differences and limits women's economic opportunities. It has been proven that mothers face consequences in the workplace for having children: "the motherhood penalty". The average wage penalties that have been found range from 5% to 10% per child among women. These changes can be explained to a degree by differences in productivity, which can be measured through indicators of human capital. (Budig & England, 2001). Therefore, the importance of policies regarding family life, such as affordable childcare and flexible work schedules, is undeniable. Such policies would help women balance family and career responsibilities and fight against the notion that they are limited to only choosing one, having to compromise either family life or economic independence.

It's everyone's problem: The importance of the economic independence of women

But why is economic independence for a modern woman so important? To begin with, the lack of financial independence within the traditional family can limit individual freedom, particularly for women who do not have full financial independence. This dependence can affect decision-making power within relationships, potentially leading to situations in which they end up having no real control.

Deeply rooted gender stereotypes can also undermine the aspirations of women, promoting a single model of family and collectively assigning them roles they are expected to fulfil in society. This can discourage women from pursuing education or advancing professionally, knowing that they will face unfair treatment and penalties if they violate gender norms. (Heilman, 2012). Contrary to the narrative that careers negatively affect women's ability to have a family and be mothers, however, a Harvard Business School study revealed that children of working mothers have been proven to be high achievers at work. (McGinn, Ruiz-Castro & Long-Lingo, 2019; Nobel, 2015). This stands as meaningful evidence that women need encouragement and real-life models to follow their dreams and fully utilize their potential.

The problem of gender inequality in the labour market gains even more nuance when realizing that the gender wage gap cannot be fully explained, even when taking into account factors such as education, experience and profession, thus becoming a puzzle that remains unsolved. The problem arises from the fact that, in many studies, after adjusting for these measurable factors, a big part of the gender pay gap still remains unexplained. Goldin highlighted this phenomenon in her gender wage-gap research, revealing that women's career choices are determined by factors that go beyond traditional explanations of human capital. It highlights the role of factors such as time flexibility, career interruptions that come about because of caring responsibilities and working practices in driving the gender pay gap. (Goldin, 1990).

In one particularly insightful study, Goldin explores why certain highly qualified professions have such big pay gaps between men and women by introducing the notion of a "glass ceiling"—a social barrier that prevents women from entering positions of power and influence within a profession. She highlights the impact of occupational division, where women and men tend to be divided into different professions, and highlights the significant role of career choices, particularly regarding working hours and flexibility, in limiting women's career potential. (Goldin & Katz, 2016). A good example of the impact that time flexibility and ability to be present for familial duties have on women's career paths over the years is the pharmacy sector. The gender gap in salary in pharmacy is smaller than in almost any other well-paying profession.

This career trend defied norms because women viewed pharmacy work as compatible with their family responsibilities: flexible work weeks, renumeration that increases linearly (rather than exponentially) with hours worked, and low pay penalties for going part-time. (Goldin & Katz, 2016).

But how do these issues that have been brought up till this point actually affect us? Although gender equality brings a lot of social and personal advantages and benefits to women, the importance of equality to all members of society is very clear even on a strictly economic level. For example, closing gender gaps in education, employment, and entrepreneurship stimulates economic growth. Gender equality has been proved to have real positive impacts on gross domestic product per capita. (European Institute for Gender Equality, n.d.). Also, gender equality promotes innovation and competitiveness. Research indicates that diverse businesses have an 83% increase in terms of innovation and 42% increase when it comes to efficient teamwork. (Deloitte, 2013).

Different countries, different outcomes

The nationwide economic benefits that come with empowering women become even clearer when countries are viewed in comparison. Countries where women have access to education, economic independence and employment manifest empirically palpable differences in levels of family well-being of their families. Such positive changes can be seen especially when comparing countries in which gender inequality is more present to countries that are taking a more progressive approach in pursuing equality and fairness in the workplace.

The country that placed last in the World Economic Forum Global Gender Gap Report from 2006 to 2021 is Yemen. In 2021, Yemen ranked amongst the five countries that had the worst standing in terms of women's economic participation, political empowerment, and educational opportunities. (World Economic Forum, 2023). The ongoing conflict has significantly impacted the nation's economy and the well-being of its people, making Yemen a focal point of international concerns and humanitarian efforts. The economy of Yemen has met a steep decline. This decline is related to the harsh realities of gender inequality in the labour market. (ACAPS, 2023). The workforce participation of women in Yemen is at only 6.2%. (World Bank, 2023). Women face obstacles in starting and sustaining businesses due to strict cultural norms, and discrimination in hiring practices and workplace environments further restricts women's economic opportunities. For example, it is not uncommon for banks in Yemen to require the permission of a male guardian for women to be able to make financial transactions. The places women can sell goods are also limited to only women-only gatherings. (ACAPS, 2023). The humanitarian crisis in Yemen contributes to gender inequalities. Limited access to healthcare and increased caregiving responsibilities alongside increasing rates of domestic abuse, all make the situation more critical for women (Baker, 2023), discouraging them from pursuing workforce participation. Today, Yemen's GDP is very low, and is part of the smaller economies of the world, currently ranked 117th. (WorldData, Indicators of economy in Yemen, 2024).

On the other hand, one of the most progressive countries in the world when it comes to gender inequality issues is New Zealand. The country is ranked 4th place in the 2022 Global Gender Gap Index and is also number five in the world for women's representation in the parliament, at 48.3%. (World Economic Forum, 2022). As a state with a strong commitment to social justice and inclusivity, New Zealand has been actively taking the initiative in adopting policies aimed at erasing gender barriers and promoting equal opportunities in the workplace. The country has implemented many legislative measures to close the gender gap and to demonstrate their commitment to diversity, such as "The Women's Employment Action Plan"— the first ever employment plan in New Zealand that has a special focus on women that are minorities. (Tan, 2023). These policies have helped New Zealand tap into the full potential of talents and skillsets that its diverse population, including women, brings to the workforce. As a result, New Zealand's forward-thinking attitudes towards gender equality, its key policies, cultural integration, and these initiatives have shown real benefits at a large scale on the labour market. 67.2% of women in New Zealand are participating in the workforce and the economy of the country is booming. (Manatu Wahine Ministry for Women, Labour market participation, n.d.). It has a highly developed free-market economy, and it is the 52nd largest economy of the world when measured by nominal gross domestic product (GDP). (WorldData, New Zealand, 2023).

As a part of its gender parity strategy, the New Zealand government has taken steps to promote gender diversity in leadership positions. Initiatives include guidelines encouraging public sector boards to have equal gender representation and the promotion of inclusive work cultures. (Manatu Wahine Ministry for Women, Equal gender representation, 2023). New Zealand is also actively working to increase the representation of women on corporate boards. Companies have launched various initiatives and recommendations toward the cause: 71% of organisations have a specific diversity strategy, and it has been shown that between 2017 and 2021, there has been a 33.3% increase in female representation in leadership positions. (Pacheco & Staninski, 2021). The country has also been actively trying to solve gender pay equity issues. (Te Kawa Mataaho Public Service Commission, 2021).

New Zealand is also ranked second place globally in the MasterCard Index of women entrepreneurs. (MasterCard, 2022). Women entrepreneurs are supported and helped through a number of resources such as Artesian, Women's Fund Grant and WEC. As a result, there has been an increasing number of women taking on entrepreneurial roles and leadership positions in start-ups. Initiatives supporting women entrepreneurs contribute to a more diverse and innovative business landscape.

It is noteworthy that, as a result of such favourable conditions, women occupy many leadership positions both in the workplace and in politics in New Zealand. Famous New Zealand female entrepreneurs include Alyona Medelyan, CEO and co-founder of Thematic; Brianne West, Founder of Ethique; Brooke Roberts, CEO and founder of Sharesies and Laura Bell, CEO and founder of SafeStack. Positive changes and initiatives in closing the gender gap can also be linked to the fact that New Zealand has female leaders at the highest political levels, with notable figures such as Helen Clark, who served as prime minister from 1999 to 2008, and Jacinda Ardern, the country's prime minister since 2017. New Zealand also has a history of active participation of women in politics. Women are widely represented in the New Zealand Parliament, and some hold key Cabinet positions. (New Zealand History, n.d.). This diversity contributes to a more inclusive policy-making process that has resulted in the implementation of more policies that help women maintain work-life balance and advance their careers, including paid parental leave, flexible working arrangements and anti-discrimination measures.

Another set of countries that would be worth comparing and analyzing are South Korea and Japan. Whereas Yemen and New Zealand represent two vastly different extremes, South Korea and Japan are both countries that have stable political environments and good economic status. The two countries are close not only geographically, but also from a cultural standpoint. Yet some important differences arise in the status of female participation in the workforce. To begin with, Japan's economy is one of the largest in the world, the GDP ranking placing it on the 4th place worldwide as of 2023. (International Monetary Fund, 2023). However, issues such as plummeting birth rates and an aging population have threatened the economic development and the sustainability of its labour market. Another issue that contributes to Japan's economic stagnation is gender inequality. In 2023, it reached its lowest ranking yet in the World Economic Health

Forum's latest Global Gender Report, especially in terms of women in leadership positions. (World Economic Forum, 2023). Japan was ranked 125th out of 148 in the Gender Gap Index, with an average gap of 22% compared to the OECD average of 12%.

Experts are expecting a worker shortage of 11 million by the year 2040. (Staffing Industry Analysts, 2023). The lack of women in influential positions and in entrepreneurship in Japan can be explained by the rigid gender stereotypes that are being promoted in its society even today. Society expects the domestic labour to be done only by women, and motherhood is considered far more important than any career. (Smirles, et al., 2020). Today, leadership is still considered a male-dominated environment: only 8% of Japanese boards consists of at least 30% women. (MSCI, 2022).

In contrast, South Korea, although similar to Japan in culture and social norms, shows a much higher rates of female entrepreneurship. Between 2013 and 2018, South Korea experienced a 200% increase in the number of female adults involved in entrepreneurship. (Buchholz, 2019). Women in South Korea reported an early-stage entrepreneurial activity rate above 10% (e.g., starting a business), more than double the rate of women in Japan (under 5%). (Elam, et al., 2022). The difference between South Korea and Japan when it comes to female entrepreneurs and women in business becomes clearer as one looks at the differences in women's attitudes and success rates. For example, Japan has extremely low rates of intentions of start-up activity and participation for women (at 2%, the lowest rate in the region of Central and East Asia), while about 25% of South Korean women expressed such intentions. (Elam, et al., 2022, at p. 67). The significantly different results despite similar cultural obstacles shows that the numerous programs that the Korean government has launched in support of female entrepreneurs has had a palpable effect. (Elam, et al., 2022). Programs such as the women's venture fostering project launched by the Korean Ministry of SMEs and Startups are of great help and successfully motivate women of all ages to take a step forward in such male-dominated fields. (beSuccess, 2023).

These successes are not limited only to the entrepreneurial field. Notably, even in the face of strict social stereotypes and discrimination, Korean women have begun to occupy positions of power and influence within the corporate world. Two of the most successful and powerful internet companies in South Korea have sought out female leadership—both Naver's CEO and Kakao's latest CEO nominee are women (Baek, 2023)—and companies such as Samsung Electronics have shown an increase in the number of women that have been appointed in leadership positions. (Hosokawa, 2022).

Such improvements of the gender equality within the workplace have real benefits for the country's economy. Although there are still many challenges to be overcome when it comes to closing the gender pay gap and discrimination, South Korea appears to be taking steps in the right direction to increase the meaningful participation of women in the workplace—an effort that will help provide a solution to collateral problems such as worker shortages in the face of an aging population. (Yoon, 2023).

Solutions underway

Seeing such drastic differences between different countries rings an alarm that there are still nations and cultures that are struggling severely with inequality and discrimination, which in turn is having negative impacts on the economy. Gender equality efforts must reach a global scale. Economic opportunities show great imbalance between countries and regions. In some regions, women are mainly employed in informal and low-wage sectors, contributing to economic inequality. Structural barriers to accessing formal employment makes progress toward gender parity much more difficult in the global workforce. The unequal allocation of resources also greatly promotes gender inequality. For instance, limited access to financial capital, technology and support for entrepreneurship all hinder women's economic action. Resource allocation becomes a critical factor in determining the extent to which women can participate and contribute to the economy of a nation. The smaller number of entrepreneurships, female-run or otherwise, results in a more vulnerable economy with fewer jobs. Legal and cultural barriers also pose significant challenges. Understanding the roots of such views and removing these barriers is essential to promoting economic inclusion.

United Nations' Sustainable Development Goals (SDGs) highlights what needs to be done to create a world with gender parity. By analysing data, they declared that it would take 300 years to end child marriages, 286 years to close gaps in legal protection and discriminatory laws and 140 years to achieve equal representation in leadership in the workplace if there are no effective measures taken. (United Nations, Overview, n.d.). Therefore, SDG 5 specifically focuses on empowering all women and girls. The project has already led to several events and initiatives taken towards the goals.

SDG 5 can be divided into several subgoals. The first is to end all forms of discrimination against women everywhere (United Nations, Targets and Indicators, n.d.), a goal that is still in need of much work, given that 55% of the countries lack laws that prohibit the direct and indirect discrimination of women (United Nations, Progress and Info, n.d.). Their second target is to eliminate all forms of violence against females in both private and public environments, including trafficking, sexual or any other type of exploitation. SDG 5 also emphasises the importance of achieving gender parity in leadership roles across various sectors, including politics, business, and public life. This involves promoting women's participation in decision-making processes at all levels. Also, adopting policies and enforceable legislation for the promotion of gender equality and the empowerment of all females at all levels is considered essential. The project encourages collaboration between public and private sectors to address the issue of gender inequality. This includes mobilising financial resources to support initiatives that promote gender equality. (United Nations, Targets and Indicators, n.d.).

Global organizations that have been making progress towards these goals. For example, UN Women works with governments and non-governmental partners to put in place policies, resources and laws in place to support women. Thirty-two UN entities encourage gender equality within their organizations, many with the research help of UN Women. (UN Women, n.d.). Another organization that works with women leaders in Vital Voices. Their economic empowerment programs help females boost their businesses and social enterprises, and they support more than 930 women leaders from 124 countries through mentoring, technical assistance, access to global networking and more. (Vital Voices, n.d.). Equality Now is a non-governmental organization that urges legal gender equality, being a founding member of the Global Campaign for Equality in Family Law as of 2020. (Equality Now, n.d.).

These projects and initiatives, amongst many others, come to show that such a positive agenda as SDG5 not only promotes the issue of gender inequality for awareness but also urges real change.

Conclusion

In conclusion, the gender gap has a significant impact on the overall well-being and prosperity of countries. When one examines the state of economic productivity and development of different countries, it is clear that gender equality in the labour market presents benefits for absolutely everyone. Reducing the gender gap in the workforce by ensuring equal pay and opportunities enhances a country's economic growth and social well-being and helps resolve issues such as worker shortages by effectively utilising the skillsets of everyone, bringing different views and perspectives that ultimately foster innovation and fairness.

Promising efforts to address issues of gender inequality include legislative measures and corporate initiatives to increase representation in leadership and to implement women-friendly policies. Indifference is part of the problem: it is easier than ever today to get involved in issues of global importance. Countries that adopt measures and support women through programs, ensuring education and actively fighting discrimination, have shown great economic progress. Businesses embracing diversity and equality practices have more success and long-term stability.

Organisations, governments and non-governmental entities must come together to implement policies that promote inclusion, remove systemic barriers and create opportunities for women everywhere. By talking openly about such real issues that affect absolutely everyone and by taking action, it is possible to remove the stigma around them. Only through such efforts can the world pave the way to a future where economic opportunity is truly gender-inclusive.

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Inflation in Romania - Cause and effect

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Abstract

Inflation is an economic process characterized by the generalized and persistent increase in the prices of goods and services in an economy, which leads to a decrease in the purchasing power of the currency. This study focuses on analyzing the effects of inflation on the population of Romania, where the investigation will include the assessment of the impact of inflation on the purchasing power of the population, the analysis of consumer behavior in the context of rising prices, and the examination of strategies adopted by companies to manage inflation. Additionally, this research provides an essential perspective on how inflation influences economic behavior and business strategies in Romania.

Keywords: inflation, economy, wages, prices.

Introduction

In the research on inflation, the focus was placed on analyzing the inflationary phenomenon from the perspective of Romania's economy, within a global context of economic growth and financial instability. The objectives of this study are to investigate the effects of inflation on the Romanian economy and to identify the mechanisms through which inflation influences consumer behavior.

The primary hypothesis of this research suggests that inflation can have different effects on various sectors of the Romanian economy and may affect the population differently depending on their socio-economic level and degree of exposure to financial risks. The secondary hypothesis assumes that inflation in Romania is primarily driven by internal factors such as monetary and fiscal policy, as well as external factors like global economic developments and changes in international trade.

In 2024, the global economy was significantly disrupted by a series of adverse factors. The war in Ukraine caused significant disruptions in the supply of energy and agricultural products, leading to price increases and widespread food insecurity. At the same time, the conflict between Israel and Hamas increased volatility in international oil markets, affecting energy price stability. Recessions in Pakistan and Argentina exacerbated regional economic instability, reducing investment flows and disrupting supply chains. Climate change has amplified the frequency and severity of extreme weather events, negatively impacting agricultural production and infrastructure. Additionally, the increase in interest rates by the US Federal Reserve (FED) had a significant impact on the global economy. The higher borrowing costs led to decreased access to financing for both companies and consumers, slowing down investments and consumer spending worldwide.

At the current stage of knowledge in the field, there is a recognition that inflation is a complex and multifactorial phenomenon, and its effective management requires a deep understanding of the interactions between the various economic and social variables involved.

Other approaches

Based on the calculations of the inflation rate in recent years conducted by the National Bank of Romania, it is evident that there has been a consistent increase in prices, especially for food and services. This trend has had a significant impact on the purchasing power of the population, disproportionately affecting low-income individuals and vulnerable families.

Basic food items, such as bread, milk, and meat, have seen substantial price increases, forcing many households to adjust their budgets and forgo certain non-essential expenses. Additionally, the costs of essential services, such as utilities and transportation, have risen, amplifying the financial pressure on consumers.

Below are some charts showing the price trends for several basic food items, such as eggs, oil and sugar:

Research methodology

To conduct this study on how inflation has affected the lives of ordinary people, a questionnaire was chosen as the data collection method. This was made available on the Google Forms platform, where participants were required to anonymously answer approximately six questions regarding the impact of inflation on their daily lives, monthly income, socio-professional category (students, employees, retirees, etc.), personal finance management, use of streaming services through monthly subscriptions, and level of knowledge about inflation. The data collection period for the study was between April 1, 2024, and April 10, 2024.

During the period, no fewer than 50 responses were collected from individuals who chose to answer the questionnaire. Additionally, follow-up discussions took place, providing supplementary data for this research.

Research result

After processing the data obtained through the Google Forms questionnaire, it was found that inflation had a significant impact on how individuals manage their incomes and expenses. Of the total study participants, 60% reported that their monthly income had not increased at the same rate as prices, leading to a decrease in purchasing power. 70% of the participants are employees, while

the rest are retirees and students, the latter being the most affected, according to the responses. Approximately 80% of participants reported that they had to adjust their budgets, cutting non-essential expenses and prioritizing the purchase of important daily food and services.

Regarding money management, 65% of participants started saving less and spending more on necessities, suggesting a trend towards reduced long-term savings. The questions about knowledge of inflation revealed that only 40% of participants fully understand the concept and mechanisms of inflation, indicating a need for financial education.

Additionally, analyzing the responses in the context of changes in the streaming services industry through monthly subscriptions, it was observed that approximately 50% of participants indicated they were affected by changes implemented by providers, either through increased subscription prices or restrictions on platform functionalities.

Besides using the questionnaire to aid in the development of this article, additional analyses were conducted on current market behavior, including how companies capitalize on the effects of inflation to maximize profits. By applying the concept of shrinkflation, companies reduce production or operating costs by decreasing the size or quantity of a product while maintaining the price or increasing it by a smaller proportion than the quantitative reduction. Consequently, products are resized or contain less raw material, yet are marketed at the same or a similar price level.

The streaming services industry has experienced a sharp rise in prices. In response to this inflation, some companies have adopted adjustment strategies, including reducing platform functionalities and introducing different subscription models along with access restrictions. For example, these restrictions may include limiting account sharing between users, restricting access to certain content, or eliminating family-specific subscription options, all aimed at maximizing profit in the face of inflation challenges.

One of these streaming platforms that has capitalized on the inflation rate as well as other socio-economic issues is Netflix. Below is a graph representing the price of the standard subscription over the years, specifically from when it launched in Romania to the present.

Conclusion

Analyzing the implications of inflation and its influence on consumer behavior and the economy, we can draw relevant conclusions. Inflation can significantly affect consumers' purchasing power, leading to budget adjustments and a reassessment of spending priorities. Within the developments in the streaming services industry, consumer reactions vary, while companies use these changes to justify subscription price increases.

These changes highlight consumers' adaptive capacity to new conditions and the need to understand the financial implications of these adjustments. In the future, research could delve deeper into how consumers respond to price variations in various sectors and analyze companies' adaptation strategies to inflation, including the development of more robust business models in the face of price volatility. Additionally, the effectiveness of government measures to manage inflation and their impact on overall economic well-being could be examined.

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