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We affirm

Contention one is American hegemony

**American adversaries dominate nuclear energy**

**Cohen 24**(Dr. Ariel Cohen, Ph.D. is a Senior Fellow at the Atlantic Council and the Founding Principal of International Market Analysis, a Washington, D.C.-based global risk advisory boutique. He is also Managing Director of the Energy, Growth, and Security Program (EGS) and a Senior Fellow with the International Tax and Investment Center (ITIC). 7 June 2024, “China And Russia Now Dominate The Global Nuclear Trade” Forbes,<https://www.forbes.com/sites/arielcohen/2024/06/07/china-and-russia-now-dominate-the-global-nuclear-trade/>, DOA: 3/5/25) LLO

Russia is not alone in surpassing the US. **China is also far ahead of the US in the nuclear energy industry. China’s nuclear power industry has retained its domestic focus, with** [**twenty-three power plants**](https://www.worldnuclearreport.org/IMG/pdf/wnisr2023-table02-reactors_under_construction.pdf) **under construction in China as of July 2023.** This is due to [increasing energy demand](https://www.iaea.org/bulletin/how-china-has-become-the-worlds-fastest-expanding-nuclear-power-producer), as China continues to develop its economy. The United States is constructing a [single nuclear power plant](https://www.statista.com/statistics/513671/number-of-under-construction-nuclear-reactors-worldwide/). **While China has refined its nuclear power production process, the last plant built in the** [**US arrived 7 years late and 17 billion dollars over budget**](https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64)**, as a testament to America’s byzantine permitting and environmental review system.** **China has built upon this expertise also to begin supplying reactors abroad. The China National Nuclear Corporation and China General Nuclear Power Group have** [**developed**](https://www.cipe.org/wp-content/uploads/2021/05/Nuclear-Dragon-Goes-Abroad.pdf) **a third-generation reactor called Hualong One.** This new reactor began operations in [2021](https://apnews.com/article/china-nuclear-power-7996f4ec51f0a70716da779eb8ff237f) in Fuqing**. In 2023,** [**China began construction**](https://www.voanews.com/a/china-begins-construction-of-pakistan-s-largest-nuclear-power-plant-/7181016.html) **on the Chashma-5 nuclear power plant in Pakistan, which will use Hualong One reactors. Such actions contribute to China’s capacity to construct infrastructure abroad and expand its influence.** The American nuclear power industry was once the world's envy, peaking with [112 operational reactors](https://www.statista.com/statistics/184981/number-of-nuclear-power-plants-in-the-us/) in 1990, with America on a path to carbon neutrality much earlier than current predictions. **34 years later, the United States has lost nearly a third of its operational nuclear reactors, has built almost no new ones, and its average reactor age is decades old. If nothing is done to rectify this, in the next 10-15 years, scores of nuclear reactors will have to be retired as their operational lifecycles end, and as a result, America will have to contend with** [**nearly 20% of its electricity capacity**](https://www.energy.gov/nuclear) **evaporating.**

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**Through Rosatom, Russia remains the global leader in nuclear reactor construction.** According to the World Nuclear Strategy Report, **as of July 2023, Russia had** [**twenty-four**](https://www.worldnuclearreport.org/IMG/pdf/wnisr2023-table02-reactors_under_construction.pdf)**. Nuclear reactors under** [**construction**](https://www.worldnuclearreport.org/IMG/pdf/wnisr2023-table02-reactors_under_construction.pdf) **in seven countries: China, India, Turkey, Egypt, Bangladesh, Iran, and Slovakia. For comparison, the US was constructing zero. Russia dominates the nuclear industry in more areas than just reactors. They also have the** [**largest**](https://www.rferl.org/a/russia-nuclear-power-industry-graphics/32014247.html) **uranium conversion and enrichment industries in the world, at 38% and 46% of international capacity**, respectively, in 2020. **This makes it a major fuel exporter as well. Russia exported** [**over $1 billion**](https://static.rusi.org/RUSI-Russian-Exports-final-web_0.pdf#:~:text=Russian%20customs%20data%2C%20sourced%20though%20a%20third-party%20commercial,exports%20to%20members%20of%20NATO%20and%20the%20EU.) **worth of nuclear energy-related products from February 2022-2024. Two of the countries in which Russia is constructing nuclear power plants, Turkey and Slovakia, are NATO members.** They are not alone amongst the collective West in enabling Russia’s nuclear dominance while ostensibly being committed to containing the Kremlin.As my colleague Wesley A. Hill wrote, Russian-enabled [geopolitical turmoil in Africa](https://nationalinterest.org/feature/russia%E2%80%99s-kitchen-chaos-west-africa-206681), which Russia is using to [try to acquire formerly French uranium assets](https://www.msn.com/en-us/news/world/russian-federation-wants-to-acquire-uranium-assets-in-niger-isw/ar-BB1nAkmN), helped force Europe to [double its import](https://bellona.org/news/nuclear-issues/2024-03-europe-russian-nuclear-fuel) of Russian uranium in 2023. The US was no better, remaining [dependent on Russian nuclear exports](https://www.ft.com/content/2c9c325e-e734-4a9f-b089-2f64deebc658) even after the war in Ukraine restarted in 2022. The US [imported Russian nuclear fuel](https://www.reuters.com/business/energy/ban-russian-uranium-aims-revive-american-supply-2024-06-04/) until May 14th, 2024, over two years after Russia’s invasion of Ukraine began, from the same entities that the White House sanctioned.

**And, America is losing influence**

**Policy Circle 24** (Policy Circle is a digital platform that offers in-depth coverage of public policy issues in governance, environment, and society. It was launched in 2020 by a group of policy experts who share a vision of promoting evidence-based policymaking and constructive policy dialogue. It also organises summits, roundtables, and online discussions to bring together policymakers, researchers, corporate executives, professionals, and other stakeholders to deliberate on policy issues. December 27, 2024 “End of American hegemony: Can the superpower reinvent power for the 21st century” Policy Circle,<https://www.policycircle.org/world/end-of-american-hegemony/>, DOA: 3/28/25) LLO

**In 2010, a** [**historian**](https://www.fairobserver.com/author/alfred-w-mccoy/) **predicted that the American hegemony might end by 2025 — not with a bang but with a whimper** **— as domestic divisions deepened and rival powers rose to challenge its authority. Today, that prediction appears prophetic** as America faces increasing pressures from within and outside. Even as the US retains military dominance and an economy capable of immense influence, **the structural underpinnings of its global power are eroding. This decline, though not necessarily terminal, signals a transition away from the so-called American Century. Historically, the US leveraged its unmatched economic strength, technological innovation, and cultural influence to dominate the post-World War II global order. However, the foundations of the American hegemony are crumbling. The US share of global GDP has steadily declined,** falling from 50% in the mid-20th century to approximately 15% today when adjusted for purchasing power parity. **The globalisation, initially championed by the US, has redistributed industrial power, with China emerging as a key beneficiary. China’s rise has reoriented global economic networks, particularly in the Global South.** In contrast to America’s interventionist foreign policy, **China has cultivated influence through infrastructure investments, soft power campaigns**, and state-sponsored media. The United States, while still a major player, has failed to present an alternative vision that resonates with developing nations, where perceptions of Chinese leadership are increasingly favourable.

**Domestic production is critical to hegemony**

**Hiltibran et al 24** (Christel Hiltibran, Director of International Policy, Climate and Energy Program, Rowen Price, Policy Advisor for Nuclear Energy, Ryan Norman, Senior Policy Advisor for Clean Energy Finance, Climate and Energy Program, Alan Ahn, Deputy Director for Nuclear, 31 January 2025, “Trump Has Been a China Hawk on Nuclear Energy. But Congress Could Compromise That During Reconciliation.”, Third Way,<https://www.thirdway.org/memo/trump-has-been-a-china-hawk-on-nuclear-energy-but-congress-could-compromise-that-during-reconciliation#:~:text=A%20strong%20US%20nuclear%20energy,valuable%20hundred%2Dyear%20geopolitical%20relationships>., DOA 3/1/2025) ESR

President **Trump has long considered himself a China hawk,** stoking a trade war with the country, supporting ever-increasing tariffs on its goods, and using aggressive rhetoric to combat its growing global influence. **But his approach has a blind spot, failing to mitigate China’s increasing dominance in the energy sector, especially in nuclear energy development and deployment**. Until we confront China’s rising role in global energy markets, **the US will continue to cede market share and lose geopolitical influence, threatening national security both in the US and among our allied nations**. The US needs a synchronized foreign policy to counter Chinese attacks on American hegemony. But since the election, **the incoming administration and Congress have signaled misaligned approaches to foreign energy policy**. The Trump Administration’s [Day 1 executive orders](https://time.com/7208691/trump-day-one-presidential-actions-executive-orders-memorandum-proclamation-explainer/) reaffirmed the President’s commitment to domestic energy production—now it’s up to Congress to ensure legislation is going to support energy goals. Nuclear Energy Must Be a Foreign Policy Priority Beyond bilateral trade barriers, the US must also dominate critical global industries to remain competitive. **There is broad consensus that investments in national defense, space, artificial intelligence, and quantum computing will help make America more secure and more prosperous. The same is true of** [**investments in nuclear energy**](https://www.thirdway.org/memo/the-global-race-for-advanced-nuclear-is-on)**. A robust domestic nuclear supply chain has corollary benefits, including reliable energy supply, that are foundational to our** [**defense**](https://www.thirdway.org/memo/nuclear-fuel-is-a-national-security-imperative) **and** [**technology sectors**](https://www.thirdway.org/blog/dawn-of-a-nuclear-era). Moreover, **the strength of our nuclear industry directly supports our competitiveness abroad, which in turn affects** [**our ability to uphold the highest global norms in nuclear security and nonproliferation**](https://nationalinterest.org/feature/why-nuclear-fuel-vital-us-national-security-interests-ukraine-and-middle-east-207782)**. Failure to compete overseas will enable China, Russia, and other rivals to** [**erode our influence on these international standards**](https://www.defensenews.com/opinion/commentary/2023/03/29/the-global-nuclear-energy-market-is-a-geopolitical-battleground/) **and cement** [**century-long geostrategic partnerships**](https://www.thirdway.org/memo/2023-map-the-world-wants-nuclear-energy-china-and-russia-are-racing-ahead) **around the world.** [**Putting the US at the forefront of global civil nuclear markets will make us stronger, more secure, and more influential on the global stage**](https://www.thirdway.org/report/nuclear-export-financing-today-and-tomorrow?utm_source=Pardot&utm_medium=email). Our adversaries understand the stakes. **China and Russia have state-owned, heavily subsidized nuclear industries that are a key part of their efforts to gain allies and influence throughout the developing world.** China and Russia view nuclear exports as a way to develop century long partnerships in Africa, Asia, and Eastern Europe. Their interest in advanced nuclear power is less about economics, and more about influence. The competition is well underway and the United States is losing. According to the International Atomic Energy Agency, [**85% of all new reactors**](https://pris.iaea.org/PRIS/worldstatistics/UnderConstructionReactorsByCountry.aspx) **currently under construction in 2024 are Russian or PRC designs; 0% are US designs.** This year, President Trump and the new Republican Congress have an opportunity to do just that—through budget reconciliation.  Trump Could Cede Critical Geopolitical “Energy Dominance” to China in His First 100 Days by Compromising America’s Nuclear Industry—But It’s Not Too Late Put simply, **if we want to outcompete China, Congress needs to continue to prioritize clean energy.** The incoming Trump administration has made no secret of its hostility to the Inflation Reduction Act (IRA) and its clean energy provisions, especially its investments in wind and solar. But despite recent bipartisan alignment in support of nuclear energy, **Trump’s agenda not only targets renewables but may also incidentally deal a significant blow to programs supporting nuclear development and demonstration in the US.** During the 117th Congress, **IRA and the Bipartisan Infrastructure Law (BIL) created tax credits, grants, and loan programs to finance the research, development, demonstration, and even the deployment of emerging clean energy technologies**, including nuclear. In a flurry of signals issued during the lame-duck period, the incoming administration and Republican Congressional leadership have made clear **that many of these programs are on the chopping block in the first 100 days of the second Trump administration**. In competition with state-backed civil nuclear programs such as China**, the US needs to bolster its federal government funding for nuclear, not decrease it.  China is churning out large reactors at home, demonstrating** (i.e., [building and operating](https://www.thirdway.org/memo/the-global-race-for-advanced-nuclear-is-on)) **advanced reactor technologies, and marketing advanced reactors cheaply along its “Belt and Road.”** To stay relevant in this race for international market share, **the US must rapidly finance the demonstration and subsequent commercialization of US nuclear small modular reactors** (SMRs) **and advanced nuclear reactors. The time is now, in the 2025 reconciliation process, to save this critical sector from opening its global market to China.** Why? **The decisions the US government makes this year will dictate whether US nuclear developers have the resources they need to keep pace and ground test these technologies. In the interest of national security and to ensure US competitiveness, Congress must robustly appropriate funding for advanced nuclear demonstrations and maintain federal programs critical to the scale-up of these technologies**. The following programs are all essential to preserve or expand during budget reconciliation.

**Affirming enables exports**

**Bowen et al 20** (Matt Bowen is a research scholar at the Center on Global Energy Policy at Columbia University School of International Public Affairs and a senior fellow at the Atlantic Council Global Energy Center. Jackie (Kempfer) Siebens is a senior policy adviser for the energy and climate program at Third Way and a senior fellow at the Atlantic Council Global Energy Center. Jennifer T. Gordon is the managing editor and senior fellow for nuclear energy at the Atlantic Council Global Energy Center. 10/7/20, “Strengthening cooperation with allies could help the United States lead in exporting carbon-free nuclear energy”, The Atlantic Council,<https://www.atlanticcouncil.org/blogs/energysource/strengthening-cooperation-with-allies-could-help-the-united-states-lead-in-exporting-carbon-free-nuclear-energy/>   //.  DOA: 3/3/25)JDE

First, **the federal government should establish a more comprehensive and coordinated interagency system focused on the development and deployment of civilian nuclear technologies**, which would **support bringing advanced nuclear power to the global market.** This would involve establishing a collaborative network of nuclear-specific staff positions embedded in the collection of government agencies that **play a meaningful role in safely and securely developing**, deploying, and exporting US energy **technologies**. Similar to the “Team USA” whole-of-government approach first initiated under the Obama Administration, a network of nuclear-specific staff positions could be located across different US agencies including: the Department of Energy, Department of State, Nuclear Regulatory Commission (NRC), White House Office of Science and Technology Policy, National Security Council (NSC), Department of Commerce, and any future Climate Office. While the Obama Administration created an NSC role to coordinate interagency nuclear policy, and the DOE report released earlier this year, [Restoring America’s Competitive Nuclear Advantage](https://www.energy.gov/sites/prod/files/2020/04/f74/Restoring%20America%27s%20Competitive%20Nuclear%20Advantage_1.pdf), recommended reinstating that role, there is currently no high-level mechanism for interagency coordination on US nuclear exports. And, **since it is difficult to export a product that lacks a domestic market, continued policy support for constructing advanced reactors here in the United States is imperative.**

**Exports secure positive global relationships**

**Graham 19** (Thomas Graham is a retired diplomat who helped negotiate every international arms control and nonproliferation agreement from 1970 to 1977, co-chair of the Nuclear Energy and National Security Coalition, 5/29/19, “National security stakes of US nuclear energy” The Hill,<https://thehill.com/opinion/national-security/445550-national-security-stakes-of-us-nuclear-energy/>, DOA: 3/4/25) ST

We have dedicated our careers to controlling the destructive potential of nuclear weapons. But since the Atoms for Peace era, **U.S. leadership in supplying peaceful nuclear energy technology, equipment, and fuel to the world has been important for world development and therefore critical for the United States to establish and enforce standards for nuclear safety, security and nonproliferation**. But in recent decades, the U.S. share of international commercial nuclear energy markets has diminished, and so with it has the United States’ ability to influence global standards in peaceful nuclear energy. The critical moment for U.S. leadership in nuclear energy is when a country is developing nuclear energy for the first time. **The supplier country and the developing country typically forge a relationship that endures for the 80- to 100-year** life of the nuclear program. Unlike a coal or gas plant**, nuclear reactors need specialized fuel and maintenance. Once established, the bilateral commercial relationship is not easily dislodged by a rival nation, providing the supplier profound and lasting influence on the partner’s nuclear policies and practices.** **Russia and China have identified nuclear energy as a strategic export, to be leveraged for geopolitical influence as well as for economic gain.** According to a recent analysis, **Russia is the supplier of more nuclear technology than the next four largest suppliers combined, and China is quickly emerging as a rival. If the United States fails to compete in commercial markets, it will cede leadership to these countries on nuclear safety, security and nonproliferation, as well as foreign policy influence.** As the competition intensifies to deliver **the next generation of nuclear power technologies**, U.S. nuclear leadership is approaching a watershed opportunity. Simpler, scalable, and less expensive, small and advanced reactors **are commercially attractive to an expanded range of markets** — particularly in Africa, Asia and the Middle East. The United States has the world’s best training and development programs, unmatched regulatory experience, and multiple small and advanced reactor designs; we should be the easy choice for the next generation of nuclear technology. But early U.S. engagement in these important geopolitical regions is critical. Without it, **Russia and China will lock up future nuclear markets through MOUs and other bilateral agreements.** And for addressing the national security risks of climate change, nuclear energy is not just an option but a necessity. Developing nations that are planning to meet power and water needs for large and growing populations must have reliable, demonstrated, zero-emission nuclear power in order to meet global climate goals as well. Advanced reactors are integral to these goals. In the United States, nuclear energy is responsible for a fifth of the United States’ total electricity and more than 55 percent of our emissions-free energy, but the pace of domestic construction of new natural gas plants far exceeds the few nuclear plants under development, and the existing fleet is retiring prematurely at an alarming rate. Which brings us back to the domestic nuclear industry**. U.S. global competitiveness and leadership are inextricably linked to a strong domestic nuclear program. Without a healthy domestic fleet of plants, the U.S. supply chain will weaken against international rivals. Russia has brought six new plants online in the past five years and has six more plants currently under construction. In the same period, China has brought 28 new plants online and has 11 others under construction. These domestic projects provide Russia and China with a robust supply chain, an experienced workforce, and economies of scale that make them more competitive in bidding on international projects. Unless we continue to innovate and build new plants, we will cease to be relevant elsewhere.** Even our own domestic energy security is supported by nuclear power. The nuclear plants operating today are the most robust elements of U.S. critical infrastructure, offering a level of protection against natural and adversarial threats that is unmatched by other plants. Because the nation’s grid supplies power to 99 percent of U.S. military installations, large scale disruptions affect the nation’s ability to defend itself. **We can regain U.S. leadership in nuclear energy. The key steps are to maintain the domestic reactor fleet, with its reservoir of know-how, and to assist American entrepreneurs in developing the next generation of the technology**.

**US hegemony deters multiple revisionists**

**Ignatieff 24** (Michael Ignatieff is Professor of History at Central European University and the author of On Consolation: Finding Solace in Dark Times (Metropolitan Books, 2021)., , “The Threat to American Hegemony is Real,” 3-15-2024, https://www.project-syndicate.org/commentary/us-western-hegemony-vulnerable-to-russian-chinese-coordinated-challenge-by-michael-ignatieff-2024-03, // accessed 10-29-2024)ops

**The post-1945 world order** – written into international law, ratified by the United Nations, and kept in place by the balance of nuclear terror among major powers – **is hanging by a thread**. The United States is divided against itself and stretched to the limits of its capabilities. Europe is waking up to the possibility that, come November, America may no longer fulfill its collective-defense obligations under Article 5 of the NATO treaty. Faced with this new uncertainty, Europe is cranking up its defense production, and European politicians are screwing up the courage to persuade their electorates that they will need to ante up 2% of their GDP to guarantee their own safety. **The Western alliance** doesn’t just face the challenge of doubling down on defense while maintaining unity across the Atlantic. It also now **faces an “axis of resistance” that might be tempted to threaten Western hegemony with a simultaneous, coordinated challenge**. The lynchpin of this axis is the Russia-China “no-limits” partnership. While the Chinese supply the Russians with advanced circuitry for their weapons systems, Russian President Vladimir Putin ships them cheap oil. **Together they have imposed autocratic rule over most of Eurasia**. If **Ukraine’s exhausted defenders are forced to concede Russian sovereignty over Crimea and the Donbas region, the Eurasian axis of dictators will have succeeded in changing a European land frontier by force**. **Achieving this will threaten every state on the edge of Eurasia: Taiwan, the Baltic countries, and even Poland**. Both **dictatorial regimes will use their vetoes on the UN Security Council to ratify conquest, effectively consigning the UN Charter to history’s dustbin**. **This partnership of dictators works in tandem with a cluster of rights-abusing renegades**, led by Iran and North Korea. The **North Koreans provide Putin with artillery shells while plotting to invade the rest of their peninsula.** The Iranians manufacture the drones that terrorize Ukrainians in their trenches. Meanwhile, **Iran’s proxies – Hamas, Hezbollah, and the Houthis – are helping Russia and China by tying down America and Israel**. Unless the US can force Israel into a long-term ceasefire, **it will find itself struggling to control conflicts on three fronts (Asia, Europe, and the Middle East)**. Not even a country that outspends its rivals on defense by two to one can maintain a war footing simultaneously across so many theaters. The idea that democracies around the world will join up with America and Europe against the authoritarian threat seems like an illusion. **Instead of joining with the embattled democracies of the Global North, the rising democracies of the Global South – Brazil, India, and South Africa – seem unembarrassed to be aligning with regimes that rely on mass repression**, the cantonment of entire populations (the Uighurs in China), and shameless murder (Navalny being only the most recent example). To be sure, **the authoritarian axis currently is united only by what it opposes: American power**. It is otherwise divided by its ultimate interests. The Chinese, for example, cannot be overjoyed that the Houthis are blocking freight traffic through the Red Sea. The world’s second most powerful economy doesn’t have all that much in common with an impoverished Muslim resistance army or with theocratic Iran. Moreover, **both Russia and China remain parasitic beneficiaries of a global economy that is sustained by US alliances and deterrence**. That is why they still hesitate to challenge the hegemon too directly. However, like sharks, they smell blood in the water. **They have not only survived US sanctions but continued to prosper, replacing their dependence on embargoed markets with new markets in Latin America, Asia, and India**. Both Russia and China have discovered that American control of the global economy is not what it once was. **This discovery of American weakness might tempt them to risk a joint military challenge**. As matters stand, **US diplomacy and deterrence have successfully kept the axis divided**. CIA Director William Burns and National Security Adviser Jake Sullivan are keeping the channels open to China. Blowback American strikes against Iran have apparently convinced the theocrats to rein in Hezbollah and the militias in Iraq – though not the Houthis, whom nobody seems able to control. It doesn’t take strategic genius to see the opportunity China and Russia might be contemplating. **If they decided to mount an overt challenge to the American order** – for example, with a coordinated, **simultaneous offensive against Ukraine and Taiwan – the US would struggle to rush weapons and technology into the breach**. **Nuclear weapons would not** necessarily **deter China and Russia from risking a coordinated attempt to take Taiwan and the rest of Ukraine**. All parties would pay a horrendous price, but **Russia has shown what it is willing to expend in Ukraine, and both China and Russia may believe that there will never be a more opportune moment to overthrow American hegemony. If they were to combine forces, we would face the most serious challenge to the global economic and strategic order since 1945**. Nobody has any idea what the world would be like on the other side of such a confrontation. We cannot even assume, as we have always done, that America would prevail if faced with a simultaneous challenge from two formidable powers. If a pessimist is someone who imagines the worst in order to forestall it, we should all be pessimists. **Keeping the authoritarian axis from becoming a full-fledged alliance should be America’s first-order priority**.

**Great power war would be detrimental**

**Clare 21** (Stephen Clare: Research Fellow at the Forethought Foundation for Global Priorities Research Fellow, November 2021, “Great Power Conflict,”<https://dkqj4hmn5mktp.cloudfront.net/Great_Power_Conflict_report_Founders_Pledge_e4124df2ac.pdf> , Founders Pledge .//. DOA: 12/11/24) TZL

This report explores issues at the intersection of international relations, conflict studies, and longtermism.l In it, we draw extensively on the mainstream international relations literature but focus specifically on understanding the potential effects of war on the long-term future. Taking **a lng-term view focuses our attention on the risk a Great Power war poses to humanity's future potential. Extinction, an unrecoverable collapse of civilization, or a permanent end to humanity's growth** and progress **would** all **destroy the long-term potential of our species**. We call events that could lead to one of **these** scenarios **existential risks** .2 Such an event, if it occurred, would be unprecedented in human history. It **would cause unimaginable suffering for everyone alive today and extinguish any possibility for trillions of our would-be descendants to live happy lives**. **Some** of these global catastrophic risks, like an asteroid impact, **are direct risks. By contrast, Great Power conflict is a risk factor**: it is **connected to multiple other risks**, and **raising or lowering the amount of conflict affects the seriousness of** the **threats** we face **in** these **other areas**. In section 4 of this report we consider several concrete pathways through which **Great Power conflict poses a global catastrophic risk**. We will sort these pathways into three broad categories. First, we consider ways in which Great Power conflict poses a risk **even without a full-blown war breaking out**. For example, **a new Cold War could hasten the development of dangerous technologies or cause a breakdown in cooperation that precludes international agreements to mitigate other existential risks**. Second, **a Great Power war could itself be a global catastrophic risk**. In an all-out war between Great Power nations, **weapons with the potential to kill everyone on earth or irreparably damage civilization could be used**. Or, **in the aftermath** of a major war, **the victorious side could** emerge as a global hegemon that is able to **use advanced technologies to lock in** its **sub-optimal values**. 3 Third, **a Great Power war could weaken humanity and leave us more vulnerable to subsequent disasters**, like a serious pandemic.

Contention two is power demand

#### US is set to lose the AI race

**Zulhusni 25** (Muhammad Zulhusni, As a tech journalist, Zul focuses on topics including cloud computing, cybersecurity, and disruptive technology in the enterprise industry. He has expertise in moderating webinars and presenting content on video, in addition to having a background in networking technology. March 24, 2025 “[Is the US losing its edge in AI?](https://techwireasia.com/2025/03/is-the-us-losing-its-edge-in-ai/)” TechWire Asia,<https://techwireasia.com/2025/03/is-the-us-losing-its-edge-in-ai/#:~:text=Major%20US%20artificial%20intelligence%20companies,DeepSeek%20R1%20become%20more%20advanced>. DOA: 4/3/25) LLO

**Major US artificial intelligence companies, like OpenAI, Anthropic, and Google, have expressed concern over China’s increasing abilities in AI development. In submissions to the US government, the companies have warned America’s edge in AI is dwindling, as Chinese models like DeepSeek R1 become more advanced.** The submissions were filed in response to a government request for input on an [AI Action Plan](https://www.whitehouse.gov/briefings-statements/2025/02/public-comment-invited-on-artificial-intelligence-action-plan/), and were made in March 2025. China’s growing AI presence DeepSeek R1, the AI model from China, has drawn attention from US developers**. OpenAI described DeepSeek as evidence that the technological gap between the US and China is closing.** The corporation described DeepSeek as “state-subsidised, state-controlled, and freely available,” and expressed concerns about China’s ability to influence global AI development. OpenAI compared DeepSeek to Chinese telecommunications company Huawei, warning that Chinese regulations could allow the government to compel DeepSeek to compromise sensitive systems or important infrastructure. OpenAI also expressed worries about data privacy, pointing out that DeepSeek’s requirements for data-sharing with the Chinese government could strengthen the state’s surveillance abilities. Anthropic’s submission focused on biosecurity, noting that DeepSeek R1 “complied with answering most biological weaponisation questions, even when formulated with a clearly malicious intent.” The willingness to generate possibly [dangerous information](https://www.unite.ai/deepseek-r1-red-teaming-report-alarming-security-and-ethical-risks-uncovered/) contrasts with the safety protocols the submissions describe as implemented in US-developed models. Competition goes beyond DeepSeek. **Baidu, China’s largest search engine, recently launched Ernie X1 and Ernie 4.5, two new AI models designed to compete with leading Western systems. Ernie X1, a reasoning model, is said to match DeepSeek R1’s performance at half the cost. Meanwhile, Ernie 4.5 is priced at 1% of OpenAI’s GPT-4.5 and has outperformed it on certain benchmarks**, according to Baidu. Both OpenAI and Anthropic framed the competition as ideological, describing it as a contest between “democratic AI” developed under Western principles and “authoritarian AI” shaped by state control. However, the recent success of Baidu and DeepSeek suggests that cost and accessibility may have a greater impact on global adoption than ideology. US AI security and infrastructure concerns **The US companies’ submissions also raised their concerns about security and infrastructure challenges linked to the technology development. OpenAI’s submission focused on the dangers of Chinese state influence over AI models like DeepSeek, while Anthropic’s submission its emphasised biosecurity concerns tied to AI capabilities. The company disclosed that its own Claude 3.7 Sonnet model demonstrated improvements in biological weapon development, highlighting the dual-use nature of advanced AI systems. Anthropic also pointed to gaps in US export controls.**

**Additionally,**

**Data center demand is skyrocketing**

**Nordquist 24** (DJ Nordquist, advisory board member at ClearPath and a senior advisor at the Center for Strategic and International Studies. She previously served as the executive director representing the United States on the Board of Directors of the World Bank Group and chief of staff at the Council of Economic Advisers in the White House. DJ is a member of Carnegie’s taskforce on U.S. Foreign Policy for Clean Energy Supply Chains. 1 November 2024, “Embracing an All-of-the-Above Strategy for Energy and Economic Development”, Carnegie Endowment for International Peace,<https://carnegieendowment.org/research/2024/10/nuclear-power-united-states-energy?lang=en>, DOA 3/1/2025) ESR

**In 2023, global energy consumption increased 2.2 percent, a significantly faster rate than its average of 1.5 percent per year in the decade of 2010–2019**.1 The **BRICS+ countries were a large part of that change, growing at double the average rate** (5.1 percent); they represented a full 42 percent of global energy consumption. In more developed Organization for Economic Co-operation and Development (OECD) countries, with slower GDP growth and diminished industrial production, consumption declined for the second year in a row (although U.S. demand has been flat).2 However, **with the increasing importance of energy-intensive** artificial intelligence (**AI**) **as a productivity-enhancing game-changer, the power needs of the** developed world, particularly the **United States** given its lead in the AI field, **will likely grow**—perhaps **exponentially. Goldman Sachs forecasts a 15 percent growth rate for data centers** (which includes AI) and that **they will increase from 3 percent of total U.S. power consumption in 2022 to 8 percent by 2030**.3 Other **new-tech industries such as electric vehicles (EVs) will also contribute to increased demands on the grid**. One tech leader, Bill Gates, clearly believes that increasing energy needs will increase the importance of baseload power; he has invested $1 billion of his own money in advanced nuclear energy (and raised nearly the same amount) via the firm TerraPower in hopes of making nuclear energy more abundant and less expensive.4 In fact, tech companies are starting to contract directly with power stations for their energy needs. For example, Amazon recently bought a nuclear-powered data center in Pennsylvania, and is also trying to close on a deal with Constellation Energy to buy energy directly from one of its nuclear plants.5 Amazon has also signed a deal with Dominion Energy to develop a small modular reactor (SMR) in Virginia.6 Google reached a 2024 deal with California-based Kairos Power to build a series of SMRs to help power its burgeoning AI needs. Supply and demand are of course playing a role.7 With U.S. plant retirements and demand increasing, prices are expected to surge, especially for reliable power. 8 So as discussion continues in the West about an energy transition, it is worth remembering that **the world simply needs more energy**—whether clean or traditional—even with improved energy efficiency. The point was made a decade ago by former U.S. president Barack Obama’s administration, which noted that the United States needed an “aggressive All-of-the-Above strategy on energy” in order to “build on . . . progress, to foster economic growth, and to protect the planet for future generations.”9 One clean source that is getting increasing attention is nuclear energy, whether produced by fission now or fusion in the future. **Nuclear produces power while emitting essentially zero greenhouse gases, similar to solar, wind, and hydroelectric energy. Nuclear is already a clean energy workhorse in the United States, generating about half of U.S. carbon-free energy while operating without intermittency—instead of being at the whim of nature like renewables**.10 It is also a safe and proven technology, with newer versions of advanced nuclear (SMRs and micro-reactors) continuing to show promise.

**But, shortages are restricting data centers**

**Patel 2025**(Sonal Patel, POWER senior editor, 3-3-2025, "The SMR Gamble: Betting on Nuclear to Fuel the Data Center Boom", POWER Magazine,<https://www.powermag.com/the-smr-gamble-betting-on-nuclear-to-fuel-the-data-center-boom/>, DOA: 3/7/2024)ET

**That has dramatically raised the stakes, igniting a desperate frenzy across both the power industry—which must generate and deliver reliable electricity for a variety of emerging large load consumers—and the data center industry, which is scrambling to procure firm scalable energy to sustain its explosive growth, now and well into the future.** The stakes are fueled by real fear. **In** [**November, research firm Gartner**](https://www.gartner.com/en/newsroom/press-releases/2024-11-12-gartner-predicts-power-shortages-will-restrict-40-percent-of-ai-data-centers-by-20270) **projected that power required for AI data centers could reach 500 TWh per year by 2027, a 2.6x increase from 2023 levels. It warned that power shortages could restrict 40% of AI data centers by 2027 and drive up energy costs.** The upfront cost of power is no longer the deciding factor for data centers, speakers at the [Sustainable Data Centers Summit in Dallas, Texas,](https://future-bridge.us/data-centers-usa/) suggested in early February. “It’s crazy because we look at like the state of Oregon is about 6 GW, and you have these large hyperscalers [asking] ‘Can I get 6 GW too?’ ” said Mohammed Hassan, senior technical program manager for Amazon Web Services (AWS) Sustainability. Hassan suggested the industry has had to rethink how it approaches energy planning and procurement completely to align with incentives, address regulatory hurdles, and secure long-term reliability. “Solar and wind has taken off in the lead. But if you look at the needs of 2045, in trying to meet the Paris Agreement, solar and wind won’t be enough, so you have to look at what’s the next step.” At the conference, speakers pointed to potential alternatives that could perform over the short term: natural gas as a “bridge fuel,” carbon capture as a potential future solution, energy storage solutions for flexibility and to promote grid resilience, and renewable diesel as a cleaner backup power option. But to meet long-term goals, the industry is willing to bet on nuclear power for its many benefits—despite the significant challenges that remain.

**Small modular reactors would meet demand**

**Obando 24** (Sebastian Obando is a reporter covering the construction industry for Construction Dive, based in Washington D.C. Prior to Construction Dive, Sebastian covered the commercial real estate industry for the National Real Estate Investor, based in New York City, as well as contributing to Forbes, covering personal investment topics. He has also appeared in Adweek, New York Post, Washington Post, among others, and interned with The Daily Caller in our nation’s capital. Sebastian is a graduate of the Philip Merrill College of Journalism at the University of Maryland. 11/25/24, “Data center boom fuels demand for nuclear projects”, Utility Dive,<https://www.utilitydive.com/news/data-center-boom-fuels-nuclear-construction-projects/733603/>   //   DOA: 3/9/25)JDE

**Tech giants are increasingly turning to nuclear power to meet the growing energy demands of the** [**data center boom**](https://www.constructiondive.com/news/data-center-demand-supply-bottlenecks/720141/)**.** For example, recent projects include Amazon’s **funding of four small modular reactors** in Washington state, Google’s agreement with Kairos Power to develop small modular reactors by 2030 and Microsoft’s power purchase agreement to restart Three Mile Island Unit 1, a nuclear power reactor near Harrisburg, Pennsylvania, that was shut down in 2019. **That connection between data centers and nuclear power plants should continue to strengthen,** said Gordon Dolven, director of data center research at CBRE, a Dallas-based commercial real estate services firm. “**This role is expected to grow, especially with advancements like small modular reactors**,” said Dolven. “[**These] offer scalable and flexible solutions to support future energy needs**.” Integration of nuclear energy into tech companies’ operations offers [new opportunities for contractors](https://www.constructiondive.com/news/fluor-profits-fall-data-center-nuclear/732436/) with specialized experience, said Fluor CEO David Constable during the firm’s third quarter earnings call. Constable recently identified small modular reactors as a key growth area, **saying “there’s a strong appetite for nuclear energy to meet incredible demand for power globally**.” He noted that “interest has never been greater.” **SMRs offer** [**significant advantages for contractors**](https://www.aboutamazon.com/news/sustainability/amazon-nuclear-small-modular-reactor-net-carbon-zero) **during the construction phase. Their modular design simplifies construction, reduces timelines and requires less land compared to traditional reactors**, according to an Amazon news release. **This makes SMRs particularly well-suited for powering data center operations, which demand reliable, around-the-clock energy to support artificial intelligence**, said Dolven. “There is growing interest in placing data centers near nuclear facilities**. This is driven by the need for a reliable, 24/7 power source to support the growing demand for data centers, especially with the rise of AI workloads**,” said Dolven. “**Nuclear power offers consistent energy with zero carbon emissions, aligning with both operational and sustainability goals**.” **Although expensive to build, nuclear power plants also offer relatively low operating costs for data center operators,** according to the [U.S. Energy Information Administration](https://www.eia.gov/todayinenergy/detail.php?id=63304). That makes them an attractive option for tech companies aiming to power energy-intensive data centers while meeting emission reduction targets. Upcoming projects Amazon agreed in October to [fund four SMR construction projects](https://www.energy-northwest.com/whoweare/news-and-info/Pages/Amazon-and-Energy-Northwest-announce-plans-to-develop--advanced-nuclear-technology-in-Washington.aspx) in Washington state in partnership with Energy Northwest. The plant will generate 320 MW in its first phase. “It’s an important area of investment for Amazon,” said Matt Garman, CEO of Amazon Web Services, in a news release. “Our agreements will encourage the construction of new nuclear technologies that will generate energy for decades to come.” Similarly, Kairos Power, a nuclear technology, engineering and manufacturing company, will develop, construct and operate a series of advanced reactor plants as [part of its agreement with Google](https://kairospower.com/external_updates/google-and-kairos-power-partner-to-deploy-500-mw-of-clean-electricity-generation/). The first SMR is set to be deployed by 2030, with plants strategically located near Google’s data centers, according to Kairos. In Pennsylvania, Microsoft also entered into a [20-year agreement](https://www.constellationenergy.com/newsroom/2024/Constellation-to-Launch-Crane-Clean-Energy-Center-Restoring-Jobs-and-Carbon-Free-Power-to-The-Grid.html) with Constellation Energy to purchase power generated by the Crane Clean Energy Center, formerly known as Three Mile Island Unit 1. The deal will supply Microsoft’s data centers in the region, and includes significant investments to restore the plant, such as the turbine, generator, main power transformer and cooling and control systems. **These projects, however, are still awaiting final regulatory approval, and contractors for the construction phases have not yet been announced. Nevertheless, the recent deals continue to showcase tech giants’ focus on nuclear energy to meet their power needs**, said Dolven. “**Nuclear energy is playing a significant role in meeting the energy demands of data centers and AI technologies**,” said Dolven. “**Its ability to provide consistent, carbon-free power makes it an ideal solution as AI workloads drive unprecedented increases in energy consumption**.”

**Government support is needed**

**Patel 2025**(Sonal Patel, POWER senior editor, 3-3-2025, "The SMR Gamble: Betting on Nuclear to Fuel the Data Center Boom", POWER Magazine,<https://www.powermag.com/the-smr-gamble-betting-on-nuclear-to-fuel-the-data-center-boom/>, DOA: 3/7/2024)ET

**From an** [**operational standpoint**](https://www.powermag.com/how-nuclear-om-is-evolving-for-the-emerging-power-paradigm/)**, co-located facilities can pose new risks**, as Nina Sadighi, professional engineer and founder of Eradeh Power Consulting told POWER. “Who’s going to insure these plants?” she asked. “That’s a huge unknown. **Right now, insurance providers are hesitant because of the regulatory and operational complexity. The traditional nuclear liability structures are built around large reactors with established operational histories, and when you introduce something novel like SMRs or microreactors, you’re dealing with a very different risk profile.**” Sadighi, though generally optimistic about nuclear’s suitability for data centers, also pointed to potential workforce-related challenges that hinge on timely deployment. “If we train nuclear workers now, but deployment gets delayed, those workers won’t wait around,” she said. “T**he nuclear workforce pipeline is not like a tech workforce, where people can pivot between roles quickly. These are specialized skills that require years of training, and if there’s uncertainty about job stability, we risk losing them to other industries entirely**,” she said. Sadighi also raised concerns about the stringent operational protocols that add to labor inefficiencies. Finally, while the data center industry isn’t solely bent on economics—and told POWER sustainability with a long-term vision is a bigger priority—scaling up will require significant investment. That has sparked all kinds of debate. [**Lux Research estimates**](https://luxresearchinc.com/resources/utilities/assessing-the-economic-promise-of-small-modular-nuclear-reactors/) **first-of-a-kind (FOAK) SMRs could cost nearly three times more than natural gas ($331/MWh versus $124/MWh) and more than 10 times more when factoring in cost overruns and delays. The firm projects SMRs won’t be cost-competitive before 2035.** “Cheap nuclear just isn’t in the cards in the next two decades,” it says. However, a recent [Idaho National Laboratory study](https://inldigitallibrary.inl.gov/sites/STI/STI/Sort_129993.pdf) suggests costs could decline as SMRs move to Nth-of-a-Kind (NOAK) production. It suggests modular construction, factory fabrication, and standardized deployment could drive efficiencies, potentially reducing costs as more units are built. Notably, the study describes an “economies-of-scale penalty crossover point” where SMRs achieve cost parity with large reactors if enough units are deployed. Deploying four 300-MW SMRs could drop costs by 20% compared to a single 1,200-MW reactor, it suggests. For now, the first real-world test of this cost curve will be [Ontario Power Generation’s BWRX-300 SMR fleet](https://www.powermag.com/nuclear-supply-chain-for-the-bwrx-300-smr-takes-shape/), which is expected to start operating by 2029. The fundamental debate is rooted in several uncertainties—which is not uncommon for emerging sectors, experts also generally pointed out. “**Tax credits—especially the clean electricity production tax credits and investment tax credits—will be vital to the commercial viability of these projects, especially considering the FOAK risk,” said Teplinsky. “DOE [U.S. Department of Energy] loan guarantees and direct financing from the Federal Financing Bank at low rates are also essential to companies’ ability to secure debt and reduce cost of capital. Grant funding to support commercial demonstrations and high-assay low-enriched uranium support are also key.**” However, Teplinsky cautioned that these incentives were in place before AI-driven data demand soared. **“[T]hey will need to remain in place in order for data center-driven advanced reactor projects to be viable,” she said. “In fact, these incentives need to expand and address some of the key issues still inhibiting large-scale advanced reactor deployment despite data center demand, such as FOAK deployment and cost overrun concerns.”**

**Shortages will kill the AI race**

**Li 2025**(FENGRONG LI, CFA, CIRA Managing Director Power, Renewables & Energy Transition (PRET) FTI Consulting, 27 February 2025, "The Powerful Duo of Nuclear and Data Centers", FTI,<https://www.fticonsulting.com/insights/articles/powerful-duo-nuclear-data-centers>, DOA: 3/7/2025)ET

**Acute power shortages and mounting resource adequacy challenges have emerged as existential threats to the AI race.** **Hyperscale and colocation data centers** — among the most energy- intensive digital infrastructures — **depend on reliable, 24/7 electricity to sustain AI workloads and cloud computing. However, intermittent, non-dispatchable generation resources dominate the interconnection queues; power constraints stall data center deployment.** **Nuclear power, with its carbon-free, high-energy output, presents a compelling solution to alleviate the bottleneck.** Large tech players and the nuclear industry have forged strategic alliances to **move new nuclear projects forward. These partnerships represent a crucial down payment on building sustainable energy infrastructures capable of supporting AI growth.** Experts at FTI Consulting have evaluated the collaboration models between these two sectors, including co-location strategies, which have gained momentum despite encountering pushbacks from market participants and regulatory bodies.

**Domestic development is necessary for the US to beat China**

**Allison and Schmidt 20** (Graham Allison is the Douglas Dillon Professor of Government at Harvard University where he has taught for five decades., Eric Schmidt, “Is China Beating the U.S. to AI Supremacy?”, Belfer Center, https://www.belfercenter.org/publication/china-beating-us-ai-supremacy, DOA 4/2/23) RK

Combining decades of experience advancing frontier technologies, on the one hand, and analyzing national security decisionmaking, on the other, we have been collaborating over the past year in an effort to understand the national security implications of China’s great leap forward in artificial intelligence (AI). Our purpose in this essay is to **sound an alarm over China’s rapid progress and the current prospect of it overtaking the United States in applying AI in the decade ahead**; to explain why **AI is for the autocracy led by the Chinese Communist Party** (hereafter, the “Party”) **an existential priority**; to identify key unanswered questions about the dangers of an unconstrained AI arms race between the two digital superpowers; and to point to the reasons why we believe that **this is a race the United States can and must win**. We begin with four key points. First, most Americans believe that U.S. leadership in advanced technologies is so entrenched that it is unassailable. Likewise, many in the American national security community insist that in the AI arena China can never be more than a “near-peer competitor.” Both are wrong. In fact, **China stands today as a full-spectrum peer competitor of the United States in commercial and national security applications of AI. Beijing is not just trying to master AI—it is succeeding. Because AI will have as transformative an impact on commerce and national security over the next two decades as semiconductors**, computers and the web have had over the past quarter century, **this should be recognized as a matter of grave national concern**.[1](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-057),[2](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-056),[3](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-055) Second, China’s zeal to master AI goes far beyond its recognition that this suite of technologies promises to be the biggest driver of economic advances in the next quarter century. **For the Party, AI is mission critical. The command of 1.4 billion citizens by a Party-controlled authoritarian government is a herculean challenge**. Since the fall of the Soviet Union, Americans have been confident that authoritarian governments are doomed to fail—eventually. But AI offers a realistic possibility of upending this proposition. **AI could give the Party** not just an escape hatch from the “end of history,”[4](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-054) but **a claim to advance a model of governance—a national operating system—superior to today’s dysfunctional democracies**. As one former Democratic presidential candidate put it: “**China is using technology to perfect dictatorship**.”[5](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-053) **It’s a value proposition that resonates with many leaders around the world**. As former Google ceo Eric Schmidt has argued: “**if the Soviet Union had been able to leverage the kind of sophisticated data observation, collection and analytics employed by the leaders of Amazon today, it might well have won the Cold War**.” Third, while we share the general enthusiasm about AI’s potential to make huge improvements in human wellbeing, the development of machines with intelligence vastly superior to humans will pose special, perhaps even unique risks. In 1946, Albert Einstein warned, “the unleashed power of the atom has changed everything save our modes of thinking, and thus we drift towards unparalleled catastrophe.” We believe the same could be said of AI. Henry Kissinger has identified these risks in what we call “Kissinger’s Specter.” In his words, **AI threatens an unpredictable revolution in our consciousness and our thinking, and an “inevitable evolution in our understanding of truth and reality**.”[6](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-052) In response to Einstein’s insight, the technologists and strategists who had built and used the bomb to end World War II joined forces to find ways to prevent a nuclear World War III. Meeting the challenges posed by AI will require nothing less. Fourth, **China’s advantages in size, data collection and national determination have allowed it over the past decade to close the gap with American leaders of this industry. It is currently on a trajectory to overtake the United States in the decade ahead. Nonetheless, if the United States will awake to the challenge and mobilize a national effort**, we believe that **it can develop and execute a winning strategy**. For many readers, AI is just the latest bright, shiny object on the technology horizon. A brief explainer to provide some further context may be helpful. **AI encompasses big data, machine learning and multiple related technologies that allow machines to act in ways humans describe as “intelligent” when we do the same thing**.[7](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-051) For example, consider gps navigation app Waze locating the best route through heavy traffic; Amazon’s eerily relevant product suggestions; or the programmed machines that now regularly defeat world masters in chess. Today’s leading information technology companies—including the faangs (Facebook, Amazon, Apple, Netflix and Google) and bats (Baidu, Alibaba and Tencent)—are betting their r&d budgets on the AI revolution. As Amazon’s Jeff Bezos said this year, “We’re at the beginning of a golden age of AI.”[8](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-050) China’s AI Surge Though still in their infancy, **AI technologies will be drivers of future economic growth and national security. From facial recognition and fintech to drones and 5g, China is not just catching up. In many cases, it has already overtaken the United States to become the world’s undisputed No. 1.** In some arenas, because of constitutional constraints and different values, the United States willfully forfeits the race. In others, China is simply more determined to win. China’s AI surge is so recent that anyone not watching closely has likely missed it. As late as 2015, when assessing its international competition, American industry leaders—Google, Microsoft, Facebook and Amazon—saw Chinese companies in their rearview mirrors alongside German or French firms in the third tier. But this changed four years ago—in 2016—when leading AI application company DeepMind fielded a machine that defeated world champion Lee Sedol in the world’s most complex board game, Go.[9](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-049) Even after several American companies’ machines had bested the chess masters of the universe[10](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-048), most Chinese remained confident that machines could never beat Go champions, since Go is ten thousand times more complex than chess. Thus, DeepMind’s decisive victory became for China a “Sputnik moment”[11](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-047)—a jolt as dramatic as the Soviet Union’s launch of the first satellite into space that sparked America’s whole-of nation surge in math and science, nasa’s creation and the original “moon shot.” Kai-Fu Lee’s book AI Superpowers offers an insightful summary of China’s engagement in the field. It began with President Xi Jinping’s personal reaction to the defeat of the world’s Go champion. Declaring that this was a technology in which China had to lead, he set specific targets for 2020 and 2025 that put China on a path to dominance over AI technology and related applications by 2030.[12](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-046) Recognizing that this would have to be led by entrepreneurial companies rather than agencies of government, he designated five companies to become China’s national champions: Baidu, Alibaba, Tencent, iFlytek and SenseTime.[13](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-045) Twelve months after Xi’s directive, investments in Chinese AI startups had topped investments in American AI startups.[14](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-044) By 2018, China filed 2.5 times more patents in AI technologies than the United States.[15](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-043) And this year China is graduating three times as many computer scientists as the United States. In contrast to nuclear weapons—where governments led in discovery, development and deployment—**AI and related technologies have been created and are being advanced by private firms and university researchers. The military establishments in Washington and Beijing are essentially playing catch-up, adopting and adapting private-sector products**. Where do these two competitors stand in the AI race today? Consider leading indicators under six key headings: product market tests, financial market tests, research publications and patents, results in international competitions, talent and national operating environments. Consumers’ choices of products in markets speak for themselves. In fintech, China stands alone. Tencent’s WeChat Pay has nine hundred million Chinese users,[16](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-042) while Apple Pay only has 22 million in the United States.[17](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-041) And when it comes to capability, **WeChat** Pay can do much more than Apple Pay. Chinese consumers use their app to buy coffee at Starbucks and new products from Alibaba, pay bills, transfer money, take out loans, make investments, donate to charity and manage their bank accounts. In doing so, they **generate a treasure trove of granular data about individual consumer behavior that AI systems use to make better assessments of individuals**’ credit-worthiness, interest in products, capacity to pay for them and other behavior. In mobile payments, Chinese spend $50 for every dollar Americans spend, in total, $19 trillion in 2018.[18](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-040) U.S. mobile payments have yet to reach $1 trillion. Credit cards are as old-fashioned to Chinese millennials as handwritten checks are to their American counterparts. Mark Zuckerberg has noticed: Facebook’s major moves last year into digital payments,[19](https://www.belfercenter.org/publication/china-beating-us-ai-supremacy#footnote-039) including the recent introduction of Facebook Pay, are copying Tencent, rather than the other way around.

**Kroenig 21** (Dr. Matthew Kroenig is a professor of government and foreign service at Georgetown University and the director of the Scowcroft Strategy Initiative at the Atlantic Council. His most recent book is The Return of Great Power Rivalry: Democracy versus Autocracy from the Ancient World to the US and China (2020), Winter 2021, “Will Emerging Technology Cause Nuclear War?” Strategic Studies Quarterly, https://www.jstor.org/stable/pdf/48638052.pdf DOA: 3/7/23) LLO

How will states use such a newfound advantage? Technology rarely fundamentally changes the nature or objectives of states. More often, states use technology to advance preexisting geopolitical aims. Moreover, enhanced power can result in greater ambition. **Given the geopolitical landscape deof the international system will behave differently with new military technologies than will revisionist powers, such as Russia and China. The spread of new technology to the United States and its Allies and partners would likely serve, on balance, to reinforce the existing sources of stability in the prevailing international system. At the end of the Cold War, the United States and its Allies and partners achieved a technological military advantage over its great power rivals, with the US using its unipolar position to deepen and expand a rules-based system.** They also employed their military dominance to counter perceived threats from rogue states and terrorist networks. **The United States, its Allies, and partners did not, however, engage in military aggression against great power, nuclear-armed rivals or their allies. In the future, these status quo powers are apt to use military advantages to reinforce their position in the international system and to deter attacks against Allies and partners in Europe and the Indo-Pacific.** These states might also employ military power to deal with threats posed by terrorist networks or by regional revisionist powers such as Iran and North Korea. **But it is extremely difficult to imagine scenarios in which Washington or its Allies or partners would use newfound military advantages provided by emerging technology to conduct an armed attack against Russia or China.** Similarly, **Moscow and Beijing would likely use any newfound military strength to advance their preexisting geopolitical aims. Given their very different positions in the international system, however, these states are likely to employ new military technologies in ways that are destabilizing. These states have made clear their dissatisfaction with the existing international system and their desire to revise it. Both countries have ongoing border disputes with multiple neighboring countries.** If Moscow developed new military technologies and operational concepts that shifted the balance of power in its favor, it would likely use this advantage to pursue revisionist aims. If Moscow acquired a newfound ability to more easily invade and occupy territory in Eastern Europe, for example (or if Putin believed Russia had such a capability), it is more likely Russia would be tempted to engage in aggression. **Likewise, if China acquired an enhanced ability through new technology to invade and occupy Taiwan or contested islands in the East or South China Seas, Beijing’s leaders might also find this opportunity tempting. If new technology enhances either power’s anti-access, area-denial network, then its leaders may be more confident in their ability to achieve a fait accompli attack against a neighbor and then block a US-led liberation. These are precisely the types of shifts in the balance of power that can lead to war.** As mentioned previously, the predominant scholarly theory on the causes of war—the bargaining model—maintains that imperfect information on the balance of power and the balance of resolve and credible commitment problems result in international conflict.52 **New technology can exacerbate these causal mechanisms by increasing uncertainty about, or causing rapid shifts in, the balance of power.** Indeed as noted above, new military technology and the development of new operational concepts have shifted the balance of power and resulted in military conflict throughout history. Some may argue emerging military technology is more likely to result in a new tech arms race than in conflict. This is possible. **But Moscow and Beijing may come to believe (correctly or not) that new technology provides them a usable military advantage over the United States and its Allies and partners. In so doing, they may underestimate Washington. If Moscow or Beijing attacked a vulnerable US Ally or partner in their near abroad, therefore, there would be a risk of major war with the potential for nuclear escalation.** The United States has formal treaty commitments with several frontline states as well as an ambiguous defense obligation to Taiwan. **If Russia or China were to attack these states, it is likely, or at least possible, that the United States would come to the defense of the victims. While many question the wisdom or credibility of America’s global commitments, it would be difficult for the United States to simply back down. Abandoning a treaty ally could cause fears that America’s global commitments would unravel. Any US president, therefore, would feel great pressure to come to an Ally’s defense and expel Russian or Chinese forces. Once the United States and Russia or China are at war, there would be a risk of nuclear escalation.** As noted previously, experts assess the greatest risk of nuclear war today does not come from a bolt-out-of-the-blue strike but from nuclear escalation in a regional, conventional conflict.53 **Russian leaders may believe it is in their interest to use nuclear weapons early in a conflict with the United States and NATO.54** Russia possesses a large and diverse arsenal, including thousands of nonstrategic nuclear weapons, to support this nuclear strategy. In the 2018 Nuclear Posture Review, **Washington indicates it could retaliate against any Russian nuclear “de-escalation” strikes with limited nuclear strikes of its own using low-yield nuclear weapons.55** The purpose of US strategy is to deter Russian strikes. **If deterrence fails, however, there is a clear pathway to nuclear war between the United States and Russia. As Henry Kissinger pointed out decades ago, there is no guarantee that, once begun, a limited nuclear war stays limited.56 There are similar risks of nuclear escalation in the event of a US-China conflict.** China has traditionally possessed a relaxed nuclear posture with a small “lean and effective” deterrent and a formal “no first use” policy. **But China is relying more on its strategic forces. It is projected to double—if not triple or quadruple—the size of its nuclear arsenal in the coming decade.57 Chinese experts have acknowledged there is a narrow range of contingencies in which China might use nuclear weapons first.58** As in the case of Russia,**the US Nuclear Posture Review recognizes the possibility of limited Chinese nuclear attacks and also holds out the potential of a limited US reprisal with low-yield nuclear weapons as a deterrent.59 If the nuclear threshold is breached in a conflict between the United States and China, the risk of nuclear exchange is real. In short, if a coming revolution in military affairs provides a real or perceived battlefield advantage for Russia or China, such a development raises the likelihood of armed aggression against US regional allies, major power war, and an increased risk of nuclear escalation.**

#### Nuclear war causes extinction

**Starr 14** (Steven Starr: Director, Clinical Laboratory Science Program at the U of Missouri. Senior scientist for Physicians for Social Responsibility. 5/30/14, “The Lethality of Nuclear Weapons: Nuclear War has No Winner”, Centre for Research on Globalization,<http://www.globalresearch.ca/the-lethality-of-nuclear-weapons-nuclear-war-has-no-winner/5385611>   //   DOA: 4/1/21)JDE

Paul Craig Roberts held top security clearances. He has repeatedly warned that a US-Russian nuclear war would wipe out the human race, along with all other complex forms of life. As a scientist with expert knowledge, I wish to echo and explain his warning.//// **Nuclear war has no winner**. Beginning in 2006, several of the world’s leading climatologists (at Rutgers, UCLA, John Hopkins University, and the University of Colorado-Boulder) published a series of studies that evaluated the long-term environmental consequences of a nuclear war, including baseline scenarios fought with merely 1% of the explosive power in the US and/or Russian launch-ready nuclear arsenals. They concluded that **the consequences of even a “small” nuclear war would include catastrophic disruptions of global climate**[i] **and massive destruction of Earth’s protective ozone layer**[ii]. These and more recent studies predict that **global agriculture would be so negatively affected by such a war, a global famine would result, which would cause up to 2 billion people to starve to death**. [iii]//// These peer-reviewed studies – which were analyzed by the best scientists in the world and found to be without error – also predict that **a war fought with less than half of US or Russian strategic nuclear weapons would destroy the human race**.[iv] In other words, a US-**Russian nuclear war would create such extreme long-term damage to the global environment that it would leave the Earth uninhabitable for humans and most animal forms of life**.//// A recent article in the Bulletin of the Atomic Scientists, “Self-assured destruction: The climate impacts of nuclear war”,[v] begins by stating://// “A nuclear war between Russia and the United States, even after the arsenal reductions planned under New START, could produce a nuclear winter. Hence, **an attack by either side could be suicidal, resulting in self-assured destruction**.” In 2009, I wrote an article[vi] for the International Commission on Nuclear Non-proliferation and Disarmament that summarizes the findings of these studies. It explains that **nuclear firestorms would produce millions of tons of smoke, which would rise above cloud level and form a global stratospheric smoke layer that would rapidly encircle the Earth. The smoke layer would remain for at least a decade, and it would act to destroy the protective ozone layer** (vastly increasing the UV-B reaching Earth[vii]) as well as block warming sunlight, thus creating Ice Age weather conditions that would last 10 years or longer.//// Following a US-Russian nuclear war, **temperatures in the central US and Eurasia would fall below freezing every day for one to three years; the intense cold would completely eliminate growing seasons for a decade or longer. No crops could be grown, leading to a famine that would kill most humans and large animal populations.//// Electromagnetic pulse from high-altitude nuclear detonations would destroy the integrated circuits in all modern electronic devices**[viii], including **those in commercial nuclear power plants. Every nuclear reactor would almost instantly meltdown; every nuclear spent fuel pool** (which contain many times more radioactivity than found in the reactors) **would boil-off, releasing vast amounts of long-lived radioactivity. The fallout would make most of the US and Europe uninhabitable. Of course, the survivors of the nuclear war would be starving to death anyway**.////

# 2AC

#### Nuclear waste is incredibly well protected

**WNA 24** (World Nuclear Association is the international organization that promotes nuclear power and supports the companies that comprise the global nuclear industry. 12 August 2024, “Radioactive Waste – Myths and Realities”, WNA,<https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-wastes-myths-and-realities>, DOA 3/11/25) RK

**Hazardous waste is produced by most major industrial processes. Of all hazardous material shipped each year in the USA, radioactive waste accounts for just 5% of the total; and of that 5%, less than 10% relates to nuclear power production**.[c](https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-wastes-myths-and-realities#Notes) Globally, about 15 million packages of radioactive material are transported each year on public roads, railways, and ships. **There has been no instance of radioactive release causing harm to people, property or the environment in many millions of transport miles**.[d](https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-wastes-myths-and-realities#Notes) The primary assurance of safety in the transport of nuclear materials is the way in which they are packaged. **Packages that store waste during transport are designed to ensure shielding from radiation and containment of waste, even under the most extreme accident conditions.** Different packaging standards have been developed by the International Atomic Energy Agency (IAEA) according to the characteristics and potential hazard posed by the different types of nuclear material. HLW shipments are made in robust 125-tonne 'Type B' casks. There has never been an accident in which a Type B transport cask containing radioactive materials has been breached or has leaked. A significant accident in the USA in 1971 demonstrated the integrity of a Type B cask, which was later returned to service. The safety features built into Type B casks are very significant. **For the radioactive material in a large Type B package in sea transit to become exposed, the ship's hold (inside double hulls) would need to rupture, the 25cm thick steel cask would need to rupture, and the stainless steel flask or the fuel rods would need to be broken open. Either borosilicate glass (for reprocessed wastes) or ceramic fuel material would then be exposed, but in either case these materials are very insoluble.**

**Rhodes 18** (Richard Rhodes, author of numerous books, including the recently published Energy: A Human History, and is the winner of the Pulitzer Prize, the National Book Award, and the National Book Critics Circle Award. Appearing as host and correspondent for documentaries on public television’s Frontline and American Experience series, he has also been a visiting scholar at Harvard, MIT, and Stanford University, 19 July 2018, “Why Nuclear Power Must Be Part of the Energy Solution”, Yale Environment 360,<https://e360.yale.edu/features/why-nuclear-power-must-be-part-of-the-energy-solution-environmentalists-climate>, DOA 3/27/2025) ESR

Third, **nuclear power releases** [**less radiation**](https://www.scientificamerican.com/article/coal-ash-is-more-radioactive-than-nuclear-waste/) **into the environment than any other** major **energy source**. This statement will seem paradoxical to many readers, since it’s not commonly known that non-nuclear energy sources release any radiation into the environment. They do. The worst offender is **coal**, a mineral of the earth’s crust that **contains** a substantial volume of the radioactive elements **uranium and thorium. Burning coal gasifies its organic materials, concentrating its mineral components into the remaining waste**, called fly ash. So much coal is burned in the world and so much fly ash produced that coal is actually the major source of radioactive releases into the environment. In the early 1950s, when the U.S. Atomic Energy Commission believed high-grade uranium ores to be in short supply domestically, [it considered](https://books.google.com/books?id=_94YOMPK1ywC&pg=PR12&lpg=PR12&dq=1950s+US+atomic+energy+commission+uranium+coal+nuclear+weapons&source=bl&ots=hTLn3y1yO2&sig=uT1yTfacHobs7a7x05VVIULZEso&hl=en&sa=X&ved=0ahUKEwia1O3KoabcAhXwmuAKHYwzAOkQ6AEIwAEwEA#v=onepage&q=1950s%20US%20atomic%20energy%20commission%20uranium%20coal%20nuclear%20weapons&f=false) extracting uranium for nuclear weapons from the abundant U.S. supply of fly ash from coal burning. In 2007, China [began exploring](http://www.world-nuclear-news.org/newsarticle.aspx?id=14224) such extraction, drawing on a pile of some 5.3 million metric tons of brown-coal fly ash at Xiaolongtang in Yunnan. The Chinese ash averages about 0.4 pounds of triuranium octoxide (U3O8), a uranium compound, per metric ton. [Hungary](http://www.wise-uranium.org/upeur.html) and [South Africa](http://www.world-nuclear-news.org/newsarticle.aspx?id=14224) are also exploring uranium extraction from coal fly ash. What are nuclear’s downsides? In the public’s perception, there are two, both related to radiation: the risk of accidents, and the question of disposal of nuclear waste. There have been three large-scale accidents involving nuclear power reactors since the onset of commercial nuclear power in the mid-1950s: Three-Mile Island in Pennsylvania, Chernobyl in Ukraine, and Fukushima in Japan. **Studies indicate even the worst possible accident at a nuclear plant is less destructive than other major industrial accidents.** The partial meltdown of the **Three-Mile Island** reactor in March 1979, while a disaster for the owners of the Pennsylvania plant, **released only a minimal quantity of radiation to the surrounding population**. According to the [U.S. Nuclear Regulatory Commission](https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html): “The approximately **2 million people** around TMI-2 during the accident are estimated to have **received an average radiation dose of only about 1 millirem** above the usual background dose. To put this into context, **exposure from a chest X-ray is about 6 millirem** and the area’s natural radioactive background dose is about 100-125 millirem per year… In spite of serious damage to the reactor, the actual release had negligible effects on the physical health of individuals or the environment.” The explosion and subsequent burnout of a large graphite-moderated, water-cooled reactor at Chernobyl in 1986 was easily the worst nuclear accident in history. Twenty-nine disaster relief workers died of acute radiation exposure in the immediate aftermath of the accident. In the subsequent three decades, UNSCEAR — the United Nations Scientific Committee on the Effects of Atomic Radiation, composed of senior scientists from 27 member states — has observed and reported at regular intervals on the health effects of the Chernobyl accident. It has identified [no long-term health consequences](http://www.unscear.org/unscear/en/chernobyl.html) to populations exposed to Chernobyl fallout except for thyroid cancers in residents of Belarus, Ukraine and western Russia who were children or adolescents at the time of the accident, who drank milk contaminated with 131iodine, and who were not evacuated. By 2008, UNSCEAR [had attributed](http://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf) some 6,500 excess cases of thyroid cancer in the Chernobyl region to the accident, with 15 deaths.  The occurrence of these cancers increased dramatically from 1991 to 1995, which researchers [attributed](http://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf) mostly to radiation exposure. No increase occurred in adults. “The average effective doses” of radiation from Chernobyl, [UNSCEAR also concluded](https://books.google.com/books?id=v3dKU51fEjYC&pg=PA220&lpg=PA220&dq=the+average+effective+doses+due+to+both+externa+an+internal+exposures+received+by+members+of+the+general+public+during+1986-2005+were+about+30+mSv+for+the+evacuees&source=bl&ots=4QXKd-Oq7I&sig=WM17_0zqqNq0SIg7VJuWdxcm1qw&hl=en&sa=X&ved=0ahUKEwjxy9SsqabcAhWMZd8KHZkyBN8Q6AEIKjAA#v=onepage&q=the%20average%20effective%20doses%20due%20to%20both%20externa%20an%20internal%20exposures%20received%20by%20members%20of%20the%20general%20public%20during%201986-2005%20were%20about%2030%20mSv%20for%20the%20evacuees&f=false), “due to both external and internal exposures, received by members of the general public during 1986-2005 [were] about 30 mSv for the evacuees, 1 mSv for the residents of the former Soviet Union, and 0.3 mSv for the populations of the rest of Europe.”  A sievert is a measure of radiation exposure, a millisievert is one-one-thousandth of a sievert. A full-body CT scan delivers about 10-30 mSv. A U.S. resident receives an average background radiation dose, exclusive of radon, of about 1 mSv per year. The statistics of Chernobyl irradiations cited here are so low that they must seem intentionally minimized to those who followed the extensive media coverage of the accident and its aftermath. Yet they are the peer-reviewed products of extensive investigation by an international scientific agency of the United Nations. They indicate that **even the worst possible accident at a nuclear power plant — the complete meltdown and burnup of its radioactive fuel — was yet far less destructive than other major industrial accidents across the past century**. To name only two: Bhopal, in India, where at least [3,800 people died immediately](https://www.theatlantic.com/photo/2014/12/bhopal-the-worlds-worst-industrial-disaster-30-years-later/100864/) and many thousands more were sickened when 40 tons of methyl isocyanate gas leaked from a pesticide plant; and Henan Province, in China, where at least [26,000 people drowned](http://en.people.cn/200510/01/eng20051001_211892.html) following the failure of a major hydroelectric dam in a typhoon. “Measured as early deaths per electricity units produced by the Chernobyl facility (9 years of operation, total electricity production of 36 GWe-years, 31 early deaths) yields 0.86 death/GWe-year),” [concludes](http://ecolo.org/documents/documents_in_english/cherno-zbigniew_fear-06.htm) Zbigniew Jaworowski, a physician and former UNSCEAR chairman active during the Chernobyl accident. “This rate is lower than the average fatalities from [accidents involving] a majority of other energy sources. For example, **the Chernobyl rate is nine times lower than the death rate from liquefied gas… and 47 times lower than from hydroelectric stations**.”  **Nuclear waste disposal**, although a continuing political problem, **is no**t any **longer a technological problem.** The accident in Japan at **Fukushima** Daiichi in March **2011 followed a major earthquake and tsunami**. The tsunami flooded out the power supply and cooling systems of three power reactors, causing them to melt down and explode, breaching their confinement. **Although 154,000 Japanese citizens were evacuated from a 12-mile exclusion zone around the power station, radiation exposure beyond the station grounds was limited**. According to the [report submitted](http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/appendices/fukushima-radiation-exposure.aspx) to the International Atomic Energy Agency in June 2011: “**No harmful health effects were found** in 195,345 residents living in the vicinity of the plant who were screened by the end of May 2011. All the 1,080 children tested for thyroid gland exposure showed results within safe limits. By December, government health checks of some 1,700 residents who were evacuated from three municipalities showed that two-thirds received an external radiation dose within the normal international limit of 1 mSv/year, 98 percent were below 5 mSv/year, and 10 people were exposed to more than 10 mSv… [There] was **no major public exposure, let alone deaths from radiation**.”  Nuclear waste disposal, although a continuing political problem in the U.S., is not any longer a technological problem. Most U.S. spent **fuel**, more than 90 percent of which could be recycled to extend nuclear power production by hundreds of years, **is stored** at present safely **in impenetrable concrete-and-steel dry casks on the grounds of operating reactors, its radiation slowly declining.  The U.S. Waste Isolation Pilot Plant** (WIPP) **near Carlsbad, New Mexico currently stores low-level and transuranic military waste and could store commercial nuclear waste in a 2-kilometer thick bed of crystalline salt**, the remains of an ancient sea. The salt formation extends from southern New Mexico all the way northeast to southwestern Kansas. **It could** [**easily accommodate**](https://99percentinvisible.org/episode/ten-thousand-years/) **the entire world’s nuclear waste for the next thousand years.**

**WNA 24** (World Nuclear Association is the international organization that promotes nuclear power and supports the companies that comprise the global nuclear industry. August 23 2024, “Safety of Nuclear Power Reactors”, WNA,<https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors>, 3/3/25) RK

A particular nuclear scenario was loss of cooling which resulted in melting of the nuclear reactor core, and this motivated studies on both the physical and chemical possibilities as well as the biological effects of any dispersed radioactivity. **Those responsible for nuclear power technology in the West devoted extraordinary effort to ensuring that a meltdown of the reactor core would not take place, since it was assumed that a meltdown of the core would create a major public hazard, and if uncontained, a tragic accident with likely multiple fatalities. In avoiding such accidents the industry has been very successful. In the 60-year history of civil nuclear power generation, with over 18,500 cumulative reactor-years across 36 countries, there have been only three significant accidents at nuclear power plants**: [Three Mile Island](https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/three-mile-island-accident) (USA 1979) where the reactor was severely damaged but radiation was contained and there were no adverse health or environmental consequences. [Chernobyl](https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident) (Ukraine 1986) where the destruction of the reactor by steam explosion and fire killed two people initially plus a further 28 from radiation poisoning within three months, and had significant health and environmental consequences. [Fukushima Daiichi](https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident) (Japan 2011) where three old reactors (together with a fourth) were written off after the effects of loss of cooling due to a huge tsunami were inadequately contained. There were no deaths or serious injuries due to radioactivity, though about 19,500 people were killed by the tsunami. Of all the accidents and incidents, only the Chernobyl and Fukushima accidents resulted in radiation doses to the public greater than those resulting from the exposure to natural sources. The Fukushima accident resulted in some radiation exposure of workers at the plant, but not such as to threaten their health, unlike Chernobyl. Other incidents (and one 'accident') have been completely confined to the plant. **Apart from Chernobyl, no nuclear workers or members of the public have ever died as a result of exposure to radiation due to a commercial nuclear reactor incident. Most of the serious radiological injuries and deaths that occur each year (2-4 deaths and many more exposures above regulatory limits) are the result of large uncontrolled radiation sources, such as abandoned medical or industrial equipment**.

#### Economy is structurally stagnating

#### Dai et al 3/19 (Sheng Dai et al: Associate professor at Zhongnan University et al. 19 March 2025, “Can Omitted Carbon Abatement Explain Productivity Stagnation?”, The review of income and wealth,<https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R> .//. DOA: 3/31/25) TZL

The **secular stagnation** of productivity growth **has** occurred in virtually all Western countries since the financial crisis that started in the US in 2008 and subsequently **led to the European debt crises and the period known as the Great Recession** (see, e.g., Syverson [2017](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0041); Crafts [2018](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0009)). Several possible explanations for productivity stagnation have been suggested in economics. Firstly, since technological progress is traditionally seen as the main driver of productivity growth, it seems natural that **the recent stagnation may be due to the slowdown of innovations.** Most notably, Gordon ([2012](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0022)) and Bloom et al. ([2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0004)) have suggested that new ideas get harder to find over time. As previous innovations have already been utilized, it **is increasingly more difficult to generate genuine innovations that would further boost productivity growth.** Bloom et al. ([2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0004)) provide evidence that links declining innovation to productivity stagnation. Secondly, since most **countries have unemployment and underutilized productive capacity, aggregate productivity slowdown could also relate to inefficient allocation of resources** in the economy. **Empirical work in the US** and Europe **suggests that business dynamism** (e.g., **firm entry, job creation, or job turnover) has been declining (**see, e.g., Decker et al. [2016](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0016); Grossman et al. [2017](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0023)), which can slow down productivity growth. Further, De Loecker et al. ([2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0015)) suggest that there have been rising markups, which further suggests that the **market power of firms has been increasing**. Such increasing market power is connected to productivity slowdown. Both declining business dynamism and rising markups can contribute to the misallocation of resources. **Previous misallocation studies** (e.g., Hsieh and Klenow [2009](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0026); Restuccia and Rogerson [2017](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0037)**) focused on comparing developing countries with the US, but during the current productivity stagnation it has been suggested that misallocation of resources might have something to do with the declining productivity** and it might be related to the previous two explanations. For example, increasing market power and markups can lead to inefficient allocation of resources. The third type of explanation refers to measurement challenges in total factor productivity (TFP). For example, the digital economy provides new goods such as information and entertainment services free of charge (e.g., Brynjolfsson et al. [2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0007)). Since free digital services and improved quality of services are not included in the conventional national accounts, measured productivity growth can be downward biased due to mismeasurement. One potentially important explanation for productivity stagnation, which relates to the broader theme of mismeasurement but has thus far attracted little attention, hinges on the ongoing transition to mitigate climate change. Specifically, reducing greenhouse gas (GHG) emissions requires massive capital investments and innovation efforts, which are included in the measured capital stock (or capital services) and labor inputs. However, such inputs do not contribute to the measured GDP. Since the conventional TFP measures ignore the social benefits of GHG abatement, the measured TFP can slow down when the inputs of the GHG abatement are included, but the outputs are excluded. The purpose of this paper is to explore whether considering GHG emissions can explain productivity stagnation in OECD countries. Our first contribution is to empirically investigate the impacts of GHG emissions, fixed capital, and human capital on productivity growth. We measure productivity growth with and without GHG emissions, compare green TFP growth based on either capital stocks or capital services and calculate green TFP growth with and without human capital. The results confirm that the measured productivity growth is considerably higher when the GHG emissions are accounted for. For countries that have reduced GHG emissions most actively, the average green TFP growth rate could double the conventional TFP growth. Further, the choice of fixed capital and human capital would also have non-negligible impacts on green TFP growth. To achieve our main purpose, the second contribution of this paper is to construct a novel quantile shadow-price Fisher index to gauge green TFP growth. The proposed quantile shadow-price Fisher index does not require the real price data for input-output variables and can avoid an ad hoc choice of quantiles which may lead to different productivity estimates and allow quantiles to move in the inter-period sample.[1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0002_14) To operationalize the proposed index, the third contribution of this paper is to develop a penalized convex quantile regression (CQR) approach to estimate shadow prices. In doing so, **we regularize the CQR approach by adding an extra regularization term on subgradients to increase the convexity of the objective function. Compared to the conventional full frontier approach, penalized CQR can guarantee the uniqueness of estimated shadow prices and take inefficiency into account explicitl**y. Furthermore, **the** **proposed approach is more robust to outliers and heterogeneity by inheriting the appealing features from quantile regression.** The rest of the paper is organized as follows. The next section presents a motivating example. Section [3](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-sec-0003) introduces the Fisher ideal TFP index and the shadow-price Fisher index and proposes the quantile shadow-price Fisher index. The newly developed penalized CQR approach is presented in Section [4](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-sec-0004). Section [5](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-sec-0005) describes the data and variables and discusses the impact of GHG emissions on productivity estimates. Section [6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-sec-0008) further discusses green productivity estimates with alternative capital and labor specifications. Section [7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-sec-0011) concludes this paper with future research avenues. A formal proof, a more detailed literature review, additional figures and tables, and shadow price estimates are provided in the [Online Supporting Information](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section). 2 A Motivating Example To gain insight, we begin with a specific industry-level example to illustrate the main ideas. In recent decades, the energy industry in Finland has experienced rapid technological and structural change, together with a massive investment in renewable wind and solar energy. The GHG emissions of this industry peaked in 2003, but decreased by 65 percent by the year 2020. The purpose of this section is to illustrate how the conventional measures of TFP fail to capture the technological progress targeted at reducing emissions. The thick black line in Figure [1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0001) plots the development of conventional TFP in Finland's electricity industry in the years 1995–2019 according to the standard growth accounting method (Bontadini et al. [2022](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0005)).[2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0003_23) Despite the rapid diffusion of technological innovations in renewable wind and solar energy and the substitution of fossil fuels by renewable biofuels in the district heat and industrial heat production, the conventional TFP measure indicates a declining trend in productivity since 2003. The average yearly productivity change in the years 2003–2019 was −2.3 percent. Since the output of energy has remained rather constant over time, the negative TFP trend is due to the capital investment in renewable energy generation. The simplest thinkable fix would be to adjust the growth accounting TFP measures for the GHG emissions. Using industry-level data from Statistics Finland,[3](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0004_24) we can simply subtract from the total value added of the industry a hypothetical social cost of the GHG emissions to estimate green TFP. To this end, we also need an estimate of the unit cost of GHG. In this example, we rely on the OECD's midpoint estimate for carbon costs, which was €60 per tonne in 2020 (considered as a low-end estimate for the year 2030).[4](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0005_25) For the sake of illustration, we also consider unit costs of €40 per tonne and €80 per tonne. The green TFP lines (in green color) in Figure [1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0001) illustrate how increasing the unit cost of GHG from zero toward the OECD's midpoint estimate and beyond results in a notable increase in green TFP. Setting the unit cost of GHG to €40 per tonne already suffices to turn the declining TFP into a modest green TFP growth. Using the OECD midpoint estimate of €60 per tonne results with the average yearly green TFP growth of 2.8 percent in 2003–2019. If the unit cost is set at €80 per tonne, the corresponding average yearly growth rate is 8.8 percent. This example also helps to illustrate the sensitivity of the green TFP estimates to the unit cost of GHG. In practice, a more objective estimation of the social cost of GHG proves a very challenging task. Moreover, climate policy involves various types of policy measures, including investment and innovation subsidies, emissions taxes, tradeable emissions permits, as well as more conventional command and control instruments, which may distort the market prices of green capital goods. These observations motivate us to consider an alternative approach that relies on the marginal products of GHG and factors of production, referred to as shadow prices. 3 Quantile Shadow-Price Fisher Index This section starts by reviewing the Fisher ideal TFP index, the Malmquist TFP index, and the shadow-price TFP index. Subsequently, a new quantile shadow-price Fisher index is proposed. Suppose there are I observations, indexed by i=1,…,I. For each observation i, y=(yi⁢1,…,yi⁢n)′∈ℝ++n, b=(bi⁢1,…,bi⁢j)′∈ℝ++j, and x=(xi⁢1,…,xi⁢m)′∈ℝ++m denote the desirable output, undesirable output, and input quantity vectors, respectively; p=(pi⁢1,…,pi⁢n)′ and w=(wi⁢1,…,wi⁢m)′ are the associated desirable output and input price vectors, respectively. For the sake of inter-period comparison, notations 0 and 1 indicate the base period and target period, respectively. A TFP index is typically defined as the ratio of the output quantity index and input quantity index. Accordingly, the Fisher ideal TFP index can be stated as F⁡(p0,1,w0,1,y0,1,x0,1)≡Fo⁡(p0,1,y0,1)Fi⁡(w0,1,x0,1)(1) Fo⁡(p0,1,y0,1)≡[p0⁢y1p0⁢y0×p1⁢y1p1⁢y0]1/2(2) Fi⁡(w0,1,x0,1)≡[w0⁢x1w0⁢x0×w1⁢x1w1⁢x0]1/2(3) where Fo⁡(p0,1,y0,1) and Fi⁡(w0,1,x0,1) are the Fisher ideal output and input quantity indices, respectively. The Fisher ideal TFP index requires neither estimation nor assumption on optimizing behavior, which is particularly convenient at the macro-level (e.g., countries, regions). In practice, however, the Fisher ideal TFP index requires market prices of all inputs and outputs (i.e., p and w) that are not always reliable or available. For example, if a market faces imperfect competition (e.g., natural monopolies) or government interventions (e.g., taxes, subsidies, tariffs), the prices of inputs or outputs would greatly deviate from their actual market prices. Notably, in the case of measuring green productivity (or environmental productivity), the non-market goods and services are modeled as inputs or outputs, but their market prices are notoriously hard to measure. Alternatively, the Malmquist TFP index is also widely used to measure TFP growth (see, e.g., Jeon and Sickles [2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0027); Zhou [2018](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0048); Odeck and Schøyen [2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0036)). For instance, the standard input-oriented Malmquist TFP index is defined as M⁡(y0,1,x0,1)≡[Di0⁡(y0,x0)Di0⁡(y1,x1)×Di1⁡(y0,x0)Di1⁡(y1,x1)]1/2(4) where Dit⁡(y,x)=sup⁡{θ>0:(x/θ,y)∈𝒯} denotes the input distance function characterizing the production possibility set 𝒯 of period t (t∈{0,1}). Färe and Grosskopf ([1992](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0017)) demonstrate that if one assumes constant returns to scale (CRS), profit maximization, and allocative efficiency of inputs x and outputs y in both periods, the Malmquist TFP index ([4](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0004)) equals the Fisher ideal TFP index ([1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0001)). However, Balk ([1993](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0002)) convincingly argues that these conditions are so strong that they are unlikely to be fulfilled in practice. Under slightly milder conditions, the Malmquist TFP index can reasonably approximate the Fisher ideal TFP index, and vice versa, even if the prices and technology change (Balk [1993](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0002)). Kuosmanen et al. ([2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0029)) propose an intermediate route between the Fisher and Malmquist TFP indices by introducing the following shadow-price Fisher TFP index. Fs⁡(ρ0,1,ω0,1,y0,1,x0,1)≡[ρ0⁢y1ρ0⁢y0×ρ1⁢y1ρ1⁢y0]1/2/[ω0⁢x1ω0⁢x0×ω1⁢x1ω1⁢x0]1/2(5) where ρ=(pi⁢1,…,pi⁢n)′ and ω=(wi⁢1,…,wi⁢m)′ are the desirable output and input shadow-price vectors. Note that there are alternative interpretations of the shadow price in the literature (Kuosmanen and Zhou [2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)). In this paper, we interpret the shadow prices ρ and ω as the subgradients of 𝒯 to y and x, respectively. Formally, we have the following equivalence relation between the Fisher ideal TFP index and the shadow-price Fisher TFP index. Theorem 1.The shadow-price Fisher TFP index ([5](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0005)) and the Fisher ideal TFP index ([1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0001)) are equivalent, if the shadow prices are unique and the allocative efficiency condition is held. Proof.See proof in Kuosmanen et al. ([2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0029)). There are well-known measurement issues with labor and capital. Quality of labor input depends on education and experience. The capital stock is an aggregate of various types of buildings, machinery, and increasingly intangible assets. Further, capital investment is inherently risky.[5](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0006_40) Regarding the prices, in many countries, the labor markets have frictions, and hence, the average wage rate and its change over time do not necessarily capture the marginal product (see, e.g., Frank [1984](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0020); Lee and Saez [2012](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0032); Webber [2015](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0043)). For capital inputs, De Loecker et al. ([2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0015)) present evidence about growing markups and monopoly power, which can also affect the accounting measures of capital stock and capital services. Therefore**, using shadow prices instead of market prices for inputs can help mitigate the negative effects of the low quality of price data for some countries.** When inputs x are not allocated efficiently, the price-based Fisher index (i.e., the Fisher ideal TFP index) may not accurately reflect the true cost of producing the desired output level, as it does not consider the opportunity cost of allocating resources away from their best alternative use. If prices are distorted by market failures, the shadow prices that capture the tradeoffs and substitution possibilities between inputs and outputs seem more relevant index weights. Nevertheless, the shadow-price Fisher TFP index has some practical limitations. First, it is not immediately obvious how the shadow-price Fisher TFP index can be applied to measure green TFP growth when considering environmental bads. Second, the shadow prices ρ and ω are generally non-unique in the conventional frontier estimation, leading to an inaccurate approximation from the shadow-price TFP index to the Fisher ideal TFP index (Balk [1993](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0002); Kuosmanen et al. [2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0029)). Third, while the shadow-price Fisher index is easy to compute whilst remaining consistent with the economic theory, it may be sensitive to random noise, heteroscedasticity, and outliers. This is because the estimated shadow prices merely rely on the conventional full frontier (e.g., the DEA frontier). Moreover, the information on inefficiency is usually neglected in shadow pricing environmental bads. To mitigate the effects of these potential biases on green TFP measure, we extend the shadow-price Fisher index ([5](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0005)) to a more generalized setting, develop an approach to ensure the uniqueness of shadow price estimates and take the inefficiency explicitly into account. Specifically, we propose the following quantile shadow-price Fisher index. Fsb⁡(ρ˜0,1,δ˜0,1,ω˜0,1,y0,1,x0,1,b0,1)≡[ρ˜0⁢y1−δ˜0⁢b1ρ˜0⁢y0−δ˜0⁢b0×ρ˜1⁢y1−δ˜1⁢b1ρ˜1⁢y0−δ˜1⁢b0]1/2/[ω˜0⁢x1ω˜0⁢x0×ω˜1⁢x1ω˜1⁢x0]1/2(6) where ρ˜, δ˜, and ω˜ are the quantile-based, locally estimated shadow prices for desirable outputs, undesirable outputs, and inputs, respectively. The local estimation of these shadow prices using quantile functions is introduced and discussed in the next section.[6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0007_48) The value of Fsb above (below) unity reveals green TFP growth (decline). Note that when introducing the undesirable outputs in productivity measure, their effects are subtracted from the desirable outputs in the quantile shadow-price Fisher index ([6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0006)), leading to a higher productivity estimate in comparison with a situation where undesirable outputs b are omitted. It is because even though the adjusted ρ˜t⁢yt−δ˜t⁢bt (t∈{0,1}) is obviously smaller than ρ˜t⁢yt, the change (ρ˜t⁢yt−δ˜t⁢bt)/(ρ˜t⁢yt−δ˜t⁢bt) tends to higher than ρ˜t⁢yt/ρ˜t⁢yt when the undesirable outputs b decrease over time, i.e., b0>b1. When x and b are not allocated efficiently (from the societal point of view), the shadow prices still capture the tradeoffs between inputs and outputs whereas the market prices are distorted. For undesirable outputs such as GHG emissions, there do exist markets for tradeable permits, but the scarcity of permits is artificially created by government regulation. The market price of emission permits would reflect the true social cost of GHG only under the strong assumption that the government regulation is socially optimal. However, the markets for tradeable permits do not cover all regions and all industries, even in those countries where markets for tradeable permits exist. If we recognize the need to shadow price the GHG emissions, for the sake of consistency, it seems better to apply the shadow prices for other inputs as well. For green TFP and TFP, we mainly care about the relative proportions of shadow prices and their change over time, not the absolute magnitudes. To pave the way to empirical estimation, the following result concerning price normalizations is worth noting. Lemma 1.Choosing desirable output y1 as a numeraire and normalizing all shadow prices of period t by the corresponding ρ˜1t does not affect the quantile shadow-price Fisher index Fsb, that is Fsb⁡(ρ˜0/ρ˜10,ρ˜1/ρ˜11,δ˜0/ρ˜10,δ˜1/ρ˜11,ω˜0/ρ˜10,ω˜1/ρ˜11,y0,1,x0,1,b0,1)=Fsb⁡(ρ˜0,ρ˜1,δ˜0,δ˜1,ω˜0,ω˜1,y0,1,x0,1,b0,1). Proof.See the Online Appendix [A.1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section). This result demonstrates that, without a loss of generality, we can choose one of the desirable outputs as a numeraire good and express shadow prices of all other outputs and inputs in terms of the numeraire. This result is particularly convenient in applications that only include a single desirable output such as the GDP. 4 Quantile Function Estimation To estimate the quantile shadow-price Fisher index ([6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0006)), in this section we develop penalized CQR to obtain the robust and unique shadow prices at each quantile and then apply this local estimation strategy to derive ρ˜, δ˜, and ω˜.[7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0008_52) The quantile shadow-price Fisher index ([6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0006)) thus can enable shadow pricing environmental bads with the efficiency level of each observation accounted. Kuosmanen and Zhou ([2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)) introduced the CQR approach for estimating shadow prices and marginal abatement costs in the general multi-input multi-output setting using the directional distance function (Chung et al. [1997](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0008)). In the special case that includes only a single desirable output y1, as in our empirical application, we can utilize Lemma [1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-mthst-0003) and simplify the directional distance function to the following reduced form econometric model yi=f⁡(xi,bi)+εi(7) where f can be interpreted as a production function and εi is a random error term.[8](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0009_57) To estimate quantile production functions, we do not assume an a priori functional form or smoothness for f but rather assume certain shape constraints such as monotonicity and concavity. That is, the function f is supposed to be a family of continuous, monotonic increasing, and/or globally concave, and/or homogeneous functions. While undesirable outputs b might appear to be modeled similar to inputs x in the econometric estimation of ([7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0007)), we do recognize that b are undesirable outputs by placing them in the nominator when computing the Fsb index. We can transform the non-parametric production function ([7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0007)) to the following conditional non-parametric quantile function Qy⁡[τ|(x,b)]=f⁡(x,b)+Fε−1⁡(τ)(8) where the quantile τ (0<τ<1) denotes that Qy splits the observed data into proportions τ below and (1−τ) above, and Fεi is the cumulative distribution function of the error term εi. Following Kuosmanen and Zhou ([2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)), for a given quantile τ, we can differentiate Qy with respect to b or x to obtain ∂Qyi∂bi=∂Qy⁡[τ|(x,b)]∂bi=θi∂Qyi∂xi=∂Qy⁡[τ|(x,b)]∂xi=βi(9) where θi and βi are referred to as the shadow prices of undesirable outputs and desirable inputs. Such shadow prices locally estimated at the level of τ can be denoted as the quantile-based shadow prices of inputs and undesirable outputs, respectively (cf. Färe et al. [1993](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0018); Dai et al. [2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0014)). To estimate the shadow prices of inputs and undesirable outputs at a given quantile τ, we can solve the following CQR problem (Kuosmanen and Zhou [2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)) minα,β,θ,ε−,ε+(1−τ)⁢∑i=1Nεi−+τ⁢∑i=1Nεi+s.t.yi=αi+βi′⁢xi+θi′⁢bi+εi+−εi−∀iαi+βi′⁢xi+θi′⁢bi≤αh+βh′⁢xi+θh′⁢bi∀i,hβi≥0,θi≥0∀iεi+≥0,εi−≥0∀i(10) where the estimated θ^ and β^ are the shadow prices of undesirable outputs and inputs at the level of τ, respectively. In the CQR problem ([10](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0010)), the first set of constraints can be interpreted as multivariate regression equations. The second set of constraints denotes a system of Afriat inequalities that impose concavity. The third set of constraints imposes monotonicity, and the last refers to the sign constraints of the error terms. Note that the error term εi in ([7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0007)) is decomposed into two non-negative components εi+ and εi− in ([10](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0010)), which capture the asymmetric deviations from the quantile production function (Wang et al. [2014](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0042)). Note that the sign constraint imposed on undesirable outputs (i.e., θi≥0) guarantees non-negative shadow prices for undesirable outputs, which follows a normative interpretation of the quantile production function as benchmark technology (cf. Hailu and Veeman [2001](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0024); Kuosmanen and Zhou [2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)). Of course, this constraint can be relaxed to allow for the weak disposability of undesirable outputs. Furthermore, problem ([10](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0010)) presents a VRS specification of the quantile production function through the intercept term αi, which is a free variable. An additional constraint that forces αi to be zero leads to a CRS specification. However, the estimated shadow prices θ^ and β^ by CQR ([10](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0010)) are not necessarily unique (Dai et al. [2023a](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0012)). To obtain the unique estimates, a natural way is to regularize the CQR problem by imposing an L2-norm regularization on the subgradients θi and βi. Given a prespecified regularization parameter γ≥0, the penalized CQR problem is formulated as minα,β,θ,ε−,ε+(1−τ)⁢∑i=1Nεi−+τ⁢∑i=1Nεi++γ2⁢∑i=1N(‖βi‖2+‖θi‖2)s.t.yi=αi+βi′⁢xi+θi′⁢bi+εi+−εi−∀iαi+βi′⁢xi+θi′⁢bi≤αh+βh′⁢xi+θh′⁢bi∀i,hβi≥0,θi≥0∀iεi+≥0,εi−≥0∀i(11) Problem ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)) has a strongly convex objective function such that the subgradients βi and θi cannot take any value for a given objective function and feasibility. For any given γ>0, the penalized CQR can ensure the uniqueness of subgradients (Theorem [2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-mthst-0005)) and even avoid the quantile crossing problem (cf. Dai et al. [2023b](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0013)). Theorem 2.The quantile shadow prices β^ and θ^ estimated by penalized CQR ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)) are unique for all γ>0. Proof.See the online Appendix [A.2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section). Note that the subgradients estimated by CQR may be unbounded at the domain boundary of a convex hull, resulting in the overfitting problem in CQR (see, e.g., Mazumder et al. [2019](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0034); Dai [2023](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0010)). Penalized CQR, on the other hand, avoids this issue effectively through the regularization in problem ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)), which presents another appealing feature of penalized CQR over CQR. Alternatively, the overfitting problem can be addressed by incorporating Lipschitz regularization into convex regression (Mazumder et al. [2019](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0034)), where an additional boundedness constraint is imposed on subgradients (e.g., ‖·‖2≤L and ‖·‖∞≤L, where L is the tuning parameter). Nevertheless, the comparative effectiveness in addressing overfitting between penalized CQR and Lipschitz CQR warrants further scrutiny. To operationalize the proposed penalized CQR approach, the value of tuning parameter γ needs to be prespecified. The standard approaches in machine learning, such as cross-validation and Stein's unbiased risk estimate, can be used to determine the optimal value of γ (see, e.g., Mazumder et al. [2019](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0034); Dai [2023](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0010)). However, any γ∗>0 is sufficient for ensuring the uniqueness of shadow prices. For sufficiently small γ, the optimal solutions to ([10](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0010)) are also the optimal solutions to ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)) due to the exact regularization property in convex quadratic programming problems (see Friedlander and Tseng [2008](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0021)). That is, a small γ could reduce the influence of regularization on β^i and θ^i as much as possible but can guarantee their uniqueness. In practice, we employ a local estimation strategy to determine the quantile-based shadow prices ρ˜, δ˜, and ω˜ when computing the quantile shadow-price Fisher index Fsb. Note that in the special case of a single desirable output, the normalized shadow price ρ˜=ρ1/ρ1 equals unity by construction. For each observation, we solve the problem ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)) for a given number of quantiles and then use the geometric mean of the shadow prices (δ˜ or ω˜) estimated on the two quantiles nearest to the observation as its shadow price. However, for those observations that fall below the lowest quantile or above the highest quantile, the shadow prices of the nearest quantile (i.e., the lowest or highest quantile) are directly used. Following Kuosmanen and Zhou ([2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0030)), we consider here 10 equidistant quantiles, i.e., τ=(0.05,0.15,…,0.85,0.95). Formally, the normalized quantile-based shadow prices δ˜/ρ1 and ω˜/ρ1 for each observation are calculated as δ˜/ρ1={(θ^iτ∗−0.1×θ^iτ∗)1/2if0.05<τ∗<0.95, 10θ^iτ∗otherwise(12) ω˜/ρ1={(β^iτ∗−0.1×β^iτ∗)1/2if0.05<τ∗<0.95,β^iτ∗otherwise(13) where τ∗ denotes the nearest quantile above the observation and τ∗−0.1 denotes the nearest quantile below the observation, as determined by the difference between ε^i+ and ε^i−. Such a local estimation strategy can make full use of the information of each observation and take the inefficiency explicitly into account. The estimation of the shadow prices θ^iτ and β^iτ can be implemented in Python using the pyStoNED package (Dai et al. [2024](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0011)) with the standard solver Mosek (10.0.40).[11, 11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0010_roiw70012-note-0011_90) 5 Quantile Productivity Measure 5.1 Data and Variables We proceed to apply the quantile shadow-price Fisher index to empirically estimate productivity growth in 38 OECD countries from 1990 to 2019. This application focuses on quantifying productivity growth estimated by the quantile shadow-price Fisher index and identifying the impacts of GHG emissions on productivity measures. We consider a baseline model specification with the following inputs and outputs: Capital input: Capital stocks at constant 2017 national prices (in millions, 2017 US$). Labor input: Total working hours (in millions of hours). Desirable output: Real GDP at constant 2017 national prices (in millions, 2017 US$). Undesirable output: Total GHG emissions excluding Land Use Change and Forestry (in million tonnes of CO 2 equivalents). The source data on capital, labor, and GDP were collected from the Penn World Table 10.01 (PWT) (Feenstra et al. [2015](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0019))[12](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0012_92) and the data on GHG emissions were from the World Bank database.[13](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0013_93) The descriptive statistics of the variables are reported in Table [C1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section) in the Online Appendix. 5.2 Quantile Productivity Analysis Since the United Nations Framework Convention on Climate Change was established in earlier 1990s, the international community has been committed to tackling climate change and proposed a series of climate actions (Kuosmanen et al. [2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0031); Dai et al. [2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0014)). Consequently, a large share of capital investments over the recent decades has been devoted to reducing GHG emissions instead of increasing GDP, while productivity slowdown has been reported in certain developed countries (see, e.g., Syverson [2017](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0041); Crafts [2018](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0009)). A natural question arises as to whether the productivity slowdown is a mismeasurement due to the omission of undesirable outputs in traditional TFP measures. Therefore, we proceed to investigate the impact of GHG emissions on productivity growth by applying the proposed quantile shadow-price Fisher index to the traditional TFP and green TFP measures. Using panel data of 38 OECD countries during 1990–2019, we solve problem ([11](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0011)) in its CRS form and subsequently obtain the quantile shadow-price Fisher index ([6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-disp-0006)). Figure [2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0002) presents the cumulative TFP and green TFP measures for the OECD countries on average. Note that we simply set γ∗=0.01 to slightly restrict the subgradients but still obtain the unique shadow prices. See the shadow price estimates in the [Online Supporting Information](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section). <<figure omitted>> As shown in Figure [2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0002), the cumulative green TFP growth closely follows the cumulative TFP growth in the early years of the sample period. However, following the Kyoto Protocol in 1997, green TFP began to diverge and showed stronger growth relative to TFP, suggesting the increased emphasis on carbon abatement among OECD countries. Both measures experience a sharp decline during the global financial crisis of 2008–2009. After the crisis, TFP growth recovers slowly but at a much lower rate than before the crisis, while green TFP resumes its relatively rapid growth trajectory, gradually and consistently widening the gap with TFP. This result strongly suggests that ignoring the massive investments in carbon abatement can indeed help to explain why the measured TFP growth has slowed down, as in contrast, the green TFP exhibits strong cumulative growth. There is strong technological progress, but a large proportion of it aims at reducing GHG emissions. Figure [3a](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0003) demonstrates the geometric average of annual productivity growth based on the quantile shadow-price Fisher index across all 38 OECD countries during 1990–2019 with and without GHG emissions.[14](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0014_105) It is evident that the average TFP growth and green TFP growth are not identical, yet they show a similar evolution path. The green TFP growth is generally higher than the TFP growth over the period 1990–2019. The largest difference between these two productivity measures occurred in 2014, with an absolute difference of 0.91 percentage points. The average absolute difference over the period amounts to 0.40 percentage points, which cannot be omitted from the productivity measure. <<figure omitted>> (a) Our estimated productivity growth per year (38 OECD countries), (b) Our estimated and official OECD productivity growth per year (24 OECD countries). Yearly comparison of alternative productivity estimates. It is worth noting **that the financial crisis has greatly affected productivity growth for OECD countries. This is because the economic crisis results in a serious problem for economic growth, which further affects both the factor inputs, especially capital investment, and GHG emissions**. The 2008 global financial crisis was accompanied by an average of 4.40% decline in green TFP for the entire OECD countries during 2008–2009. Although this crisis was a major shock, the TFP effect was temporary. In contrast, GHG abatement efforts have relatively modest short-term effects, but **the persistence of abatement has a large effect on long-term growth.** Figure [3b](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0003) compares the geometric average productivity growth **between our quantile shadow-price Fisher TFP estimates and the official OECD measures across 24 Western OECD countries during 1990–2019.**[15](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0015_107) Our TFP estimates generally align with the official OECD measures, but are consistently slightly lower than the official measures across most of the observed period. In the CRS setting with two inputs, TFP growth essentially depends on the relative weights assigned for labor and capital. The comparison result implies that our estimated shadow prices tend to assign a higher weight for capital and a lower weight **for labor than the cost shares in the traditional residual-based method** used by the OECD. This is because the capital input exhibited much higher growth than the labor input in all OECD countries during this period. Figure [4](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0004) describes the yearly average productivity growth with and without GHG emissions at the country level. Several interesting findings are worth noting. First, the traditional TFP measure tends to underestimate productivity growth, even during a period of carbon reduction or the financial crisis. There is a noticeable difference in productivity growth between the TFP measures for all countries (0.36 percentage points; the absolute difference between green TFP and TFP), especially for transition economies such as the Czech Republic (1.15) and Lithuania (1.18). After the Kyoto Protocol came into effect in 2005, most countries reduced GHG emissions according to their commitments. Notably, the GHG emissions of Denmark, Finland, and the United Kingdom decreased by 42%, 36%, and 34%, respectively, during 2006–2019. However, this period still witnessed varying degrees of upward difference between the green TFP and traditional TFP measures, indicating that neglecting the impact of GHG emissions will overestimate the contribution from conventional factor inputs and, in turn, underestimate productivity growth. This finding is consistent with Jeon and Sickles ([2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0027)), Yörük and Zaim ([2005](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0047)), and Shen et al. ([2017](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0040)), which also note that the traditional TFP index undervalues the Luenberger green TFP index for OECD countries. Overall, the productivity growth slowdown may partly be explained by the carbon reduction efforts by OECD countries. Second, **productivity growth depends on** the GHG emissions reduction relative to the other two factor inputs. Under the Kyoto Protocol, OECD countries invest much more **capital in facilitating low-carbon transition** by utilizing cleaner production technologies, switching to cleaner fuels, or establishing market-based instruments (e.g., emissions trading systems). That is, if a country is willing to reduce GHG emissions even by a small proportion, then more conventional inputs are needed and they will increase far faster than the GHG emissions abatement. In this case, the green TFP growth will be higher than the TFP growth; in other words, the GHG emissions reduction leads to a greater enhancement in productivity growth than the other two conventional inputs. Third, **the countries from the transition economies can serve as the benchmark in terms of green development. The transition economies have relatively higher productivity growth than other OECD countries**, particularly when introducing the GHG emissions in the entire sample period, indicating that these countries utilize the resources more efficiently but emit relatively lower GHGs. A similar finding has been detected in Kuosmanen et al. ([2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0031)). However, these advantages would fade away under the double constraints of the global financial crisis and the GHG emissions reduction targets, as reflected by the low green TFP growth from 2006 to 2019 in transition economies. Fourth, for countries that have reduced GHG emissions most actively, the average green TFP growth rate could double the conventional TFP growth. For example, Estonia reduced more than twice GHG emissions (the largest decrease in percentage values) during the sample period, and the productivity growth increased from 0.18% (TFP growth) to 0.62% (green TFP growth). However, for the countries that are continuously increasing GHG emissions, the difference between TFP growth and green TFP growth is relatively small. For example, Australia's GHG emissions increased by 16.9%, and the country saw only a 0.19 percentage point difference between green TFP and TFP growth. Finally**, there exists a large variance in both green TFP and TFP growth among OECD countries (cf. Dai** [**2023**](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0010)**), suggesting that the GHG emissions reduction has not been cost-efficient and that there is a lack of coordination between economic growth, environmental protection, and resources utilization. Therefore, the current policy to improve productivity growth is inefficient, and resource misallocation across the OECD countries exists** (as will be further demonstrated below). Figure [5](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0005) compares the average green TFP growth measured by the quantile shadow-price Fisher index under the CRS and VRS specifications. It reveals that the productivity growth estimates are robust to the CRS or VRS specification. Specifically, the median absolute difference between the CRS- and VRS-based green TFP growth is 0.33 percentage points. The largest difference appears in Finland (9.5; 2004–2005), and the smallest difference is close to zero for 2.2% of all the observations with 4-digit decimal accuracy. Further, there are only 65 cases (5.9%) where the absolute value is greater than 2 percentage points, and there are 81.9% of the sample where the difference is less than 1 percentage point (see Figure [C1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section) in the Online Appendix). <<figure omitted>> Since the relative prices of labor and capital can be inferred from the PWT data, we next examine the magnitude of allocative inefficiency by calculating the ratio μ=ω˜Lω˜K/wLwK where μ denotes the allocative efficiency score (Musau et al. [2021](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0035)). If μ=1, there is no resource misallocation; if μ≠1, it suggests potential inefficiencies in the allocation of capital and labor. Table [1](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-tbl-0001) reports the descriptive statistics of the market price ratio (wL/wK) and the shadow price ratio (ω˜L/ω˜K). On average, the market price ratio is higher than the shadow price ratio under both TFP and green TFP specifications, which suggests **that the allocation of capital and labor is inefficient at the OECD level. The difference tests also show that there is a statistically significant difference between the market price ratio and the shadow price ratio, confirming the observed allocative inefficiencies for OECD countries.** <<figure omitted>> a The non-parametric Li test is applied to analyze the difference between two distributions, where the null hypothesis is that the comparative distributions are equal in their entire support (Li et al. [2009](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0033)). \*\*\* p<0.01. Figure [6](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0006) displays the evolution of the average allocation inefficiency at the OECD level. All the years exhibit allocative inefficiencies, as all the points in the figure are less than 1 and are distributed within the range of 0.15 to 0.55 in both TFP and green TFP specifications. A possible explanation for the allocative inefficiencies is that a large proportion of capital is allocated to the abatement of GHG emissions. Therefore, in the case of resource misallocation, shadow prices seem more suitable than market prices for measuring productivity growth. <<figure omitted>> 6 Alternative Model Specifications To examine the impact of different forms of physical capital inputs, we compare the baseline model with an alternative specification in which capital input is represented by capital services. We also compare the baseline model with an extended specification that includes human capital to examine the impact of human capital accumulation. 6.1 Capital Services Reliable figures for fixed capital are crucial for a better understanding of productivity growth, but they are often denoted by two interrelated but distinct concepts: Capital stocks and capital services. The former refers to the stock of physical assets at a point in time, whereas the latter represents the flow of services created by these assets in a period. Compared to capital services, capital stocks are less relevant for measuring productivity growth and are more likely to overestimate TFP growth (see, e.g., Schreyer [2001](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0038); Schreyer [2004](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0039)). In this subsection, we are primarily interested in the impact of alternative representations of fixed capital (capital stocks vs. capital services) on the green TFP growth estimates obtained from the quantile shadow-price Fisher index approach. In practice, we calculate the capital services per country per year (r⁢k⁢n⁢a⁢2i,t) by using r⁢k⁢n⁢a⁢2i,t={(1−l⁢a⁢b⁢s⁢hi,t)×r⁢g⁢d⁢p⁢n⁢ai,tt=2017;[(1−l⁢a⁢b⁢s⁢hi,2017)×r⁢g⁢d⁢p⁢n⁢ai,2017]×r⁢k⁢n⁢ai,tt≠2017 where l⁢a⁢b⁢s⁢h denotes the share of labor compensation in GDP at current national prices, r⁢g⁢d⁢p⁢n⁢a represents the real GDP at constant 2017 national prices (in millions, 2017US$), and r⁢k⁢n⁢a is the capital services at constant 2017 national prices (2017 = 1). The data of the above variables were also collected from PWT. Figure [C2](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#support-information-section) in the Online Appendix illustrates the difference between the capital services and the capital stocks for all OECD countries, where capital services grew significantly faster than capital stocks during the sample period. Figure [7](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0007) depicts the scatter plot of green TFP growth estimated with capital services vs. capital stocks. If an observation (i.e., an OECD country) is located below the 45-degree line (i.e., the red dot line), then the green TFP growth with capital services is smaller in terms of the average value than that with capital stocks. Obviously, the green TFP growth with capital stocks is generally higher than that with capital services from 1990 to 2019. This suggests that if the fixed capital input is denoted by capital stocks**, the growth of green TFP could be overestimated, while the contribution of capital assets to economic growth could be underestimated.** This finding is in **line with the traditional TFP growth analysis (see, e.g., Schreyer** [**2001**](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0038)**; Schreyer** [**2004**](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0039)**). <<figure omitted>> At the country level, we also observe that the proxy of fixed capital has non-negligible impacts on the green TFP measure. Table** [**2**](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-tbl-0002) **reports the average green TFP growth and economic growth for** three **example** countrie**s.** For instance, Italy's annual green TFP declined by 0.11% from 2010 to 2019 when estimated with capital services, but grew by 0.52% when estimated with capital stocks. Over the same period, the capital services of Italy grew by 0.66% per year, which was higher than the increase in capital stocks (0.59%). **The resulting 0.07 percentage points difference translated to the 0.63 percentage points adjustment to the green TFP measure. Therefore, the green TFP growth of Italy was overestima**ted with capital stocks**. The overestimation can also be observed in all other countries** or periods. <<figure omitted>> 6.2 Human Capital Inspired by endogenous growth models, **extensive empirical studies have demonstrated the positive externalities of human capital on TFP growth** (see, e.g., Barro [2001](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0003); Henderson and Russell [2005](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0025); Bowlus and Robinson [2012](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0006)). Recently, several studies have highlighted various potential environmental benefits of human capital accumulation (see, e.g., Yao et al. [2020](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0046); Angrist et al. [2023](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0001)), which may help to reduce GHG emissions and affect green productivity. We thus, in this subsection, incorporate human capital into quantile production functions to investigate the impact of human capital on green TFP measures. Note that human capital is proxied by the average years of schooling in the population aged 25 years and older.[16](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-note-0018_137) Figure [8](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0008) shows the estimated densities of green TFP growth with human capital for 1991, 2001, 2011, and 2019. A relatively larger discrepancy in the overall distribution appeared in 2019, indicating that the cross-country differences in green TFP growth have become larger. Furthermore, the center of the four distributions does not shift rightward. That is, the green TFP does not always grow with time in OECD countries, even though human capital is considered in the production model. <<figure omitted>> Figure [9](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-fig-0009) depicts the average green TFP growth with and without human capital for each OECD country. If an observation is located below the 45-degree line (i.e., the red dot line), then the green TFP growth with human capital is larger than that without human capital. Furthermore, if human capital is reasonably well measured, an increase in green TFP growth after considering human capital in the quantile production function indicates a relative shortage of human capital (or measurement error in labor input, equivalently). Similarly, a decrease in green TFP growth can be interpreted that there exists sufficient or even redundant human capital (Henderson and Russell [2005](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0025)). <<figure omitted>> Overall, more points are located below the 45-degree line, indicating that the green TFP growth can increase after incorporating human capital. This suggests that the **neglect of human capital** or the mismeasurement of labor input **in production models underestimated green productivity**. Notably, the **largest green TFP growth improvements driven by considering human capital** occurred in relatively developed countries such as Iceland, Italy, and Japan, as well as the transition economies (e.g., the Czech Republic and Slovenia). This finding is consistent with Henderson and Russell ([2005](https://onlinelibrary.wiley.com/doi/10.1111/roiw.70012?af=R#roiw70012-bib-0025)), which investigates the impact of human capital on country-level efficiency estimation. We also observe that several developed countries such as Canada, Luxembourg, and South Korea have decreased green TFP growth after the inclusion of human capital, indicating that the human capital

growth in these countries is poised to be saturated and sufficient.

On debt

#### . T: Nuclear industry increases economic growth

**Nessen and Brun 24** (Joseph C. Von Nessen is a research economist in the Division of Research at the Darla Moore School of Business where he specializes in regional economics, regional economic forecasting and housing economics. He regularly conducts a wide variety of economic impact analyses, feasibility studies and independent market research projects for clients in both the private and public sector. Lukas Brun is Managing Director of Research and Economic Development for E4 Carolinas, the trade association for energy companies and energy-related organizations in the Carolinas. He manages federal grants investigating the future of alternative fuel vehicles, advanced nuclear technologies, green hydrogen, and clean energy grid hardware in the Southeast. February 2024, “The Economic Impact of the Nuclear Industry in the Southeast United States”, E4 Carolina, https://www.commerce.virginia.gov/media/governorvirginiagov/secretary-of-commerce-and-trade/va-n uclear/E4\_Carolinas\_Economic\_Impact\_Report\_Final.pdf, DOA: 3/7/2025) SMB

**The nuclear industry makes sizeable and unique contributions to the region’s economy. Nuclear power plants, in particular, currently employ a sizable workforce and support large, extensive supply chain networks throughout the local regions in which they are located. These supply chain networks, in turn, generate significant economic ripple effects across many industries that are far higher than in most other industry sectors. These ripple effects include additional indirect job creation that supports higher incomes for local residents and a substantial increase in overall economic activity. This section of the report documents the economic impact of the nuclear industry in the Southeastern United States, with a specific focus on the states of Georgia, North Carolina, South Carolina, Tennessee, and Virginia – including all ongoing operations and associated business activities.** There have been multiple previous impact studies that have examined the size and scope of the nuclear industry at both the regional and national level in recent years. At the national level, the most frequently published research comes from the United States Department of Energy’s (DOE) annual release of its U.S. Energy & Employment Report, which estimates the direct employment base of the nuclear industry alongside a broader assessment of the economic impacts resulting from electric power generation. Additionally, the Nuclear Energy Institute, the World Nuclear Association, as well as many private research groups have all assessed the economic impact of the U.S. nuclear industry using a variety of overlapping methodologies as they seek to quantify and focus on different components of the industry.i The economic impact of the nuclear industry in the Southeastern United States that is most closely associated with the approach taken in this study is the Carolinas’ Nuclear Cluster CELDi Project Report 2012-2013 conducted by Clemson University in 2013, which focused exclusively on the states of North and South Carolina. The study was completed during a period in which there was active construction of new nuclear reactors in and around the Carolinas two-state region as well as before the cessation of all activities at the V.C. Summer nuclear station in Jenkinsville, South Carolina. As such, the composition of the nuclear industry has changed substantially in the years since, requiring an updated assessment of the economic impact of the region. Finally, there have been various economic assessments that have examined the specific impacts of individual national lab sites along with related professional service, supplier, and research & development firms around the country that support the nuclear industry. The studies include the ongoing nuclear-related activities at the facility being examined, but are generally focused on examining the total impact of the facility, including non-nuclear activities. As a result, these studies tend to overestimate the contribution of these facilities to the nuclear industry alone. All organizations encompassing the nuclear industry as defined above collectively employ a large workforce and support an extensive supply chain network throughout the five-state region in order to facilitate their ongoing operations. **The expenditures made by these organizations with local businesses and suppliers as well as through wages and salaries paid to employees introduce new spending activity at a statewide and regional level that would not exist otherwise. As a result, the presence of the nuclear industry in each state provides a stable base of activity that also helps contribute to long-run economic growth. Economic impacts can be divided into** **direct, indirect, and induced impacts. Direct effects are based on the activity of the nuclear power plant itself, typically described in terms of employment at, or sales generated by, a facility. Indirect effects are based on the supply chain effects of a facility, in our example, a nuclear power plant. For example, when a nuclear power plant purchases goods and services from one of its vendors, this vendor experiences an increase in demand. To satisfy this demand, it must then hire more workers and increase purchases from its own suppliers. These suppliers then experience an increase in demand, and so on. Thus, the initial dollars that are spent by the nuclear power plant are re-spent over and over again through a supplier network, which is known as the indirect effect. A similar effect – known as the induced effect – occurs with the employees of the nuclear power plant and its suppliers. These workers spend part of their incomes in the local economy, thereby increasing the demand for a variety of goods and services (such as dining, transportation, or recreation).**

On energy economy

**Aylmer 25** (Jack Aylmer, energy correspondent, 12 March 2025, “US solar industry saw record growth in 2024, but faces uncertain future”, SAN,<https://san.com/cc/us-solar-industry-saw-record-growth-in-2024-but-faces-uncertain-future/>, DOA 4/2/2025) ESR

What challenges is the US solar industry facing? The report also outlines [industry concerns](https://www.msn.com/en-us/news/other/surging-solar-industry-hopes-to-avoid-conflict-with-trump-s-energy-agenda/ar-AA1AIFVK?ocid=finance-verthp-feeds) about potential **policy shifts under** President Donald **Trump**, particularly **regarding renewable energy tax credits and funding provisions** from the Biden-era Inflation Reduction Act. The **Trump** administration **has signaled intentions to roll back** these **incentives, which played a key role in supporting the industry’s expansion.** What happens next? Projections made by the SEIA and Wood Mackenzie suggest that total U.S. solar capacity could reach 739 gigawatts by 2035, enough to power more than 550 million homes. However, the two organizations warn that **if clean energy policies are** [**significantly altered**](https://cleantechnica.com/2025/03/11/the-us-solar-industry-is-setting-records-but-the-dark-clouds-of-doom-are-gathering/)**, solar deployment could decline by 130 gigawatts over the next decade**, potentially leading to an estimated $250 billion in lost investment.

**Teirstein 25** (Zoya Teirstein is a staff writer covering the impacts of climate change on human health. Her work can also be found in Rolling Stone, Wired, and the Associated Press. She has received awards from the Indigenous Journalists Association, the SEAL Awards, and the Society of Environmental Journalists, and completed reporting fellowships with SciLine, the National Tropical Botanical Garden in Hawai‘i, and the Woods Hole Oceanographic Institution. Most recently, she was a 2022-2023 National Science-Health-Environment Reporting fellow, 3/4/25, “How Trump’s trade war could impact US electricity prices — and state climate plans” Grist, https://grist.org/energy/trump-tariffs-canada-trade-war-electricity-prices-utility-bills-climate-plans/, DOA: 3/31/25) ST

On Tuesday, **President Donald Trump initiated a trade war with Canada and Mexico, America’s two largest trading partners. Following through on weeks of threats, he imposed 25 percent tariffs on imported goods from Mexico and Canada and a lower 10 percent tariff on imports of Canadian energy resources.** (Update, Thursday, March 6: Trump has announced a one-month delay on the tariffs on most Mexican and some Canadian goods.) **Canada and Mexico’s leaders quickly struck back. Canadian Prime Minister Justin Trudeau unveiled an immediate 25 percent tariff on $20.5 billion worth of goods from the United States and promised to extend the tax to another $85 billion in products in late March. Mexican President Claudia Sheinbaum announced she also planned to unveil retaliatory tariffs this coming Sunday. Trump’s tariffs, which are widely expected to raise prices for U.S. consumers, are also poised to upend the American electricity market. All U.S. power grids except for Texas’ have some level of interconnection with grids in Canada, the largest energy supplier to the U.S. Historically, the U.S. has imported roughly twice as much power from Canada as it exports there, though that ratio has started to shift in recent years as climate change-driven drought has slowed the output of hydroelectricity in provinces like Quebec and Ontario**. **Some 98 percent of America’s natural gas imports, and 93 percent of its electricity imports — much of that from hydroelectric dams — come from Canada. America’s reliance on Canadian power is not evenly distributed.** Northern energy grids are generally more reliant on Canada’s energy resources than southern grids due to their geographic proximity to Canada. States like New York and Minnesota have also entered into energy market agreements with Canadian provinces to receive their hydroelectricity in order to meet ambitious and rapidly-approaching climate change goals. From Canada’s perspective, withholding or taxing energy exports to the U.S. is an effective bargaining chip — perhaps one of the country’s most powerful. “I see energy as Canada’s queen in this game of chess,” Andrew Furey, the premier of Newfoundland and Labrador, said in January, when Trump had not yet followed through on his threat of Canadian tariffs. Furey’s province is one of five that supplies the U.S. with hydropower. On the evening before the tariffs took effect, Doug Ford, the premier of Ontario, threatened to cut off energy exports to the United States full stop “with a smile” if Trump continues to target Canada with tariffs. On Tuesday, Ford announced a 25 percent export tax on power Ontario ships via transmission lines to 1.5 million homes in three states — Michigan, Minnesota, and New York — and said a full export ban was still on the table. All three states affected by Ontario’s export tax have climate targets on the books that rely in some measure on hydroelectric power. Minnesota, Michigan, and New York all aim to achieve clean electricity grids by 2040. Michigan is relying in large part on its own hydroelectric facilities, but Minnesota and New York are, to varying degrees, dependent on Canada to reach their targets. Experts told Grist it’s too soon to say what Trump’s tariffs, and Ford’s retaliatory measures, mean for these states’ climate goals — and their residents. “**When you’re adding unnecessary friction into the market, of course you’re going to see price increases,” said** Daniel A. Zarrilli, who served as chief climate policy advisor to former New York City mayor Bill de Blasio**. “Tariffs are going to flow to the consumer, either directly or indirectly.**” Zarrilli noted that it’s unclear what those price hikes might look like, and who — ratepayers, utilities, or some combination of actors — will shoulder them. The trade war may be felt especially acutely in New York, where developers are extending a transmission line from Quebec all the way to Queens in order to pump much-needed hydroelectric power into New York City. Once the Champlain Hudson Power Express is operational in 2026, New York City is guaranteed hydroelectric power during the summer months. It is not, however, guaranteed that reliable power during the winter. As the state has electrified its power grid, energy demand has been increasing during the cold weather months. New York power grid operators are preparing for demand during the winter to double over the next 30 years. But whether the state gets the hydropower it needs to provide reliable, renewable power during that peak demand now depends on how the trade war plays out. “**The fallout could be actually catastrophic,” s**aid Adrienne Esposito, executive director at the nonprofit Citizens Campaign for the Environment, which has helped push New York City to adopt a climate plan that mirrors the state’s. “It defies logic.”

**Halverson 22** (Cadet Halverson is a sophomore at the Air Force Academy. He was previously enlisted as a Cyberspace Operations Airman. He is studying Behavioral Science. He is interested in serving as an Information Operator or Pilot. Aug 25 2022, “The United States Must Pursue Greater Nuclear Energy Power Generation”, Air University, https://www.airuniversity.af.edu/Wild-Blue-Yonder/Articles/Article-Display/Article/3126436/the-united-s tates-must-pursue-greater-nuclear-energy-power-generation/, DOA 3/1/25) RK

**Our reliance on fossil fuels also challenges our economic security. Rising hospitalizations due to our dirtier air will lead to higher healthcare costs, placing a strain on Americans’ wallets. Crop failures, coastal cities dealing with rising sea levels, and an increased level of natural disasters are just some of the factors that will damage our economic output, costing the United States up to 10.5 percent of its GDP by 2100**.[3] Dependency on fossil fuels is a threat to our national and economic security and warrants a response.**Nuclear power is one alternative to fossil fuels that will provide the United States with more security. Nuclear power currently provides 20 percent of the United States’ power output, and it produces little to no greenhouse gas emissions**.[4] **With advancements in nuclear reactor technology, it has the potential to produce much more energy in a more efficient manner.One of the greatest potentials for nuclear energy is the advancement of small transportable reactors**.[5] **These small, portable reactors give nuclear energy the potential to provide energy for remote rural communities.**

**ONE 24** (Office of Nuclear Energy, agency of the US Department of Energy, 13 June 2024, “5 Reasons Nuclear Is a Good Neighbor”, US Department of Energy,<https://www.energy.gov/ne/articles/5-reasons-nuclear-good-neighbor#:~:text=An%20average%20plant%20employs%20between,via%20federal%20and%20state%20taxes>, DOA 3/27/2025) ESR

Reason #4: **Nuclear is good for business** Nuclear energy drives job creation. **The U.S. nuclear energy sector directly employs 60,000 people in high-quality, long-term jobs — many of which don’t require a college degree.** It takes thousands of workers to build a nuclear power plant. **An average plant employs between 500 and 800 people with salaries 30 percent higher than the local average**. According to NEI, **for every 100 nuclear power plant jobs, 66 more jobs are created in the community**. And nuclear **plants contribute billions of dollars every year to their communities via federal and state taxes.** A national [survey](https://www.bisconti.com/blog/9th-national-survey-of-nuclear-power-plant-neighbors) of communities with nuclear power plants found that **over 90 percent of neighbors believe that nuclear energy provides good jobs for local people and helps the local economy.** And in communities considering a transition from coal to nuclear, **converting a retired coal plant to a nuclear power plant** [**could lead to additional annual economic activity**](https://www.energy.gov/ne/articles/8-things-know-about-converting-coal-plants-nuclear-power) **of $275 million.**