Net Loss: An econometric method to measure the impact of Internet shutdowns

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The economic costs of Internet shutdowns are far-reaching and widespread, and span beyond the simple disruption to communication networks that are reliant on access to the Internet. Existing work on the impacts of the Internet shutdowns does not extensively exploit the fact that they can have adverse effects on the local economy in terms of output, employment, and investments. There is a lack of rigorous economic analysis of the impacts of shutdowns that can be more broadly applied to specific regions that account for variations in the intensity (or type) of shutdowns, as well as go beyond providing broad GDP cost estimates which may be misleading. This paper aims to bridge this gap by providing an econometric approach to estimate the impact of Internet shutdowns on GDP, employment, and foreign direct investment using panel data on 92 countries. We show that a point increase in the likelihood of an Internet shutdown was statistically significantly associated with a 15.6 percentage point reduction in the GDP per capita on average and every additional day of an Internet shutdown costs $86.58 per person on average.

CCS Concepts: • **Security and privacy → Economics of security and privacy**; • **Applied computing → Economics**; • **Social and professional topics → Technology and censorship**; *Universal access.*

Additional Key Words and Phrases: Internet shutdowns, service blocking, Gross Domestic Product

1 INTRODUCTION

Internet disruptions, often referred to as Internet shutdowns, are very often government-ordered instructions with the aim to intentionally block access to the Internet or sections of the Internet such as social media platforms [1, 2]. The purpose is to disrupt communications and restrict citizens' access to information in order to limit what those citizens can see, do, or communicate using the Internet platform. Internet shutdowns can broadly be classified into full network shutdowns (where access to the Internet is disrupted in a localized region or the entire country), bandwidth throttling (where Internet speeds are reduced or disrupted for a prolonged period of time), and service-based blocking (where specific content or services such as YouTube may be blocked). Each of these different types of shutdowns presents varying implications for Internet access in a country, for a given level of duration and intensity[3].

Due to the increasing reliance of businesses and trade on digital technologies [4], mandated shutdowns can have serious impacts on most economic sectors. Shutdowns may lead to the disruption of financial transactions, commerce, industry, labor markets and the availability of platforms for the delivery of services [5, 6]. Moreover,

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shutdowns create a climate of uncertainty for investments, which can prove disastrous for companies and for start-up ecosystems in particular [7]. Shutdowns can also undermine the flow of remittances to low-income and middle-income countries [8]. Economic shocks provoked by shutdowns are felt over long periods of time, greatly worsening pre-existing social economic inequalities.

There have been a range of studies that attempt to estimate the economic cost of Internet shutdowns, providing an economic value foregone due to the lack of access to the Internet during a particular period of time. However, the economic impacts of Internet shutdowns are potentially under or overestimated due to the fact that there is still a considerable gap in the availability of reliable data [9]. These models typically rely on a series of computations and a "formula" that provides a number on the basis of a set of parameters. The most prominent of these, arguably, is what is known as the "Brookings" method [5], which defines a formula for six different types of Internet shutdowns (National, subnational, mobile national, mobile subnational, national free app, subnational free app). This formula accounts for the duration of the shutdown, measures of the digital economy, the extent of the coverage and penetration of the Internet, and a multiplier effect on the digital economy.

While it is useful to determine broad-level macroeconomic impacts [7, 10] in specific country contexts, such a model precludes careful investigation of channels, mechanisms, and heterogeneity in economic impact (i.e., how they might differ across different contexts and settings). In this paper, we aim to build on this work by developing an econometric framework for estimating the implications of Internet shutdowns on a range of economic, social, and other outcomes of interest globally. There are two main contributions of adopting this type of framework: (a) it allows us to identify the contexts in which Internet shutdowns might be associated with economic outcomes; and (b) it allows us to explore a wider range of economic outcomes beyond traditional measures of economic output (e.g., the Gross Domestic Product, or GDP) [1].

Specifically, our key research questions are as follows: (RQ1:) What are the factors that are associated with the incidence of Internet shutdowns across the world?; and (RQ2:) What are the associated impacts of such Internet shutdowns on macroeconomic indicators such as the Gross Domestic Product (GDP), Foreign Direct Investment (FDI), and Unemployment rates?

Among the major econometric challenges in addressing these RQs is that of identification as well as isolating potential mechanisms between Internet shutdowns and economic outcomes. For instance, countries where Internet penetration and service provision varies, there may be variations in both the incidence of Internet shutdowns as well as subsequent economic impacts. Incorporating them in such analyses is not straightforward since in practice it is difficult to attribute causality. While we are unable to directly address this issue, we incorporate Internet characteristics in heterogeneous analyses. Unlike prior work looking at the economic impact of Internet shutdowns on the economy, we also account for other country-specific and time-specific factors that could affect economic and social outcomes to isolate the role of Internet shutdowns and expand the possible economic indicators used to measure impacts. Finally, to the best of our knowledge, this is first attempt to systematically examine the impact of Internet shutdowns using an econometric framework globally using publicly available data. In doing so, we are able to examine how mandated shutdowns can have economic impacts that should be considered by policymakers around the world when considering such disruptions to the Internet.

The remainder of the paper is structured as follows. Section 2 provides some background on the taxonomy of Internet Shutdown and explores the gaps in the current literature dealing with the economic costs of shutdowns. Section 3 contains the description of the datasets used and variables captured for use in the econometric framework for estimating the impact of Internet shutdowns. Section 4 outlines the empirical framework and challenges in implementing this estimation strategy. It also lays out the estimating equations for the shutdown risk (likelihood of an Internet shutdown) as well as the downstream associations with economic outcomes. Section 5 provides

[1]We are also among the first to use publicly available datasets and transparently outline the precise econometric model used to examine the associated impacts of Internet shutdown on economic outcomes.

the key findings and results for both the incidence of Internet shutdowns as well as economic impacts. Section 6 concludes, outlines limitations of the current work, as well as avenues for future work in estimating the impact of Internet shutdowns using this framework.

2 BACKGROUND AND LITERATURE

2.1 A brief history of Internet shutdowns

The imposition of Internet shutdowns is not a new phenomenon, however, the scale at which they have been deployed and increasingly resorted has raised concerns, especially among human rights organizations, civil societies, media organizations, and other advocacy groups. For example, according to the #KeepitOn Internet shutdowns report (coined as "Weapons of Control, Shields of impunity"), in 2022 alone there were 62 shutdowns in 16 countries during protests, 8 shutdowns in 6 countries claiming to prevent exam cheating, 33 shutdowns during active conflicts and 5 shutdowns in 5 countries tied to elections [11]. These findings are also corroborated by the Internet Shutdowns tracker at the Internet Society's Pulse[2]. Most of these shutdowns (if not all) are attributed to trying to hide human rights abuses as well as cases where there is evidence of violence, including murder, torture, rape, or apparent war crimes committed by governments, military, and police or security forces. Figure 1 shows an overview of global Internet shutdowns from 2019 to 2022, with India recording 418 cases of both regional and national shutdowns.

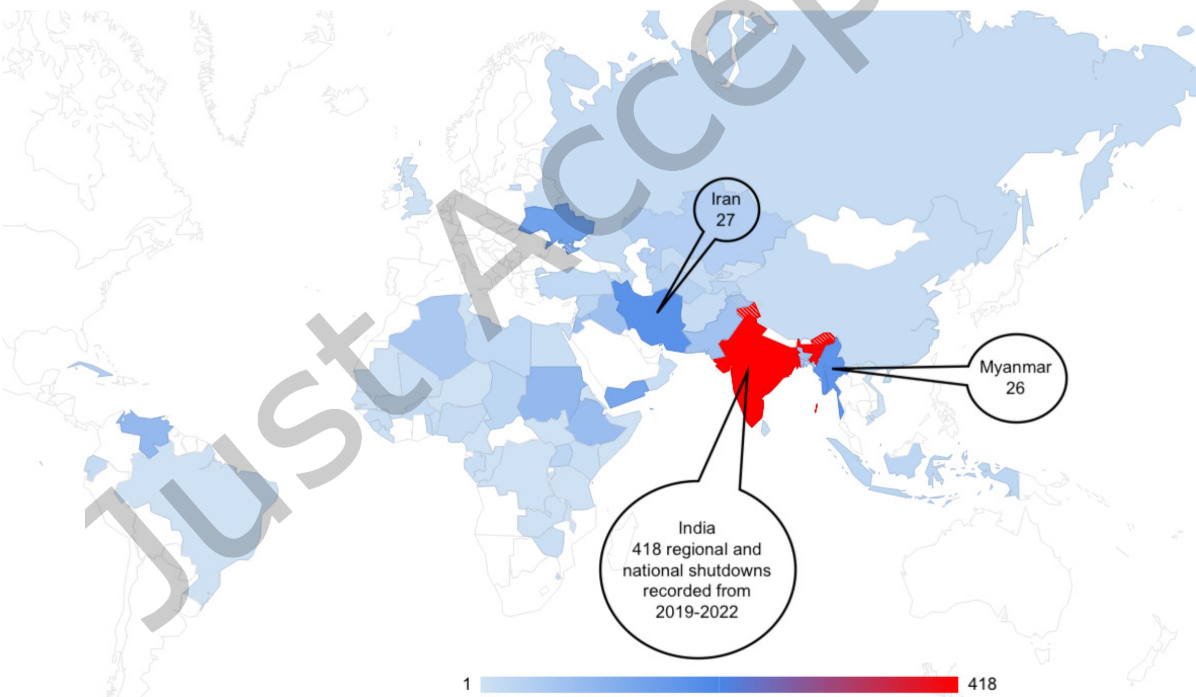

Fig. 1. Internet shutdowns around the world (2019-2022). (Source: #KeepitOn)

[2]Internet Society's Pulse Internet Shutdown Tracker - https://pulse.internetsociety.org/shutdowns

Feldstein [12] also shows that government shutdowns in 2021 largely occurred in response to or in association with four types of events: mass demonstrations, conflict and military coups, elections, and school exams (purportedly to prevent cheating). A fifth category includes ongoing repression and state responses to communal violence or religious holidays (see table 1).

Table 1. Countries and associated Internet shutdown event type in 2021 (Source: [12])

Internet shutdown Event	Countries
Protests	Bangladesh, Burkina Faso, Chad, Colombia, Cuba, Eswatini, Gabon, India, Iran, Jordan, Kazakhstan, Pakistan, Russia, Senegal, South Sudan, and Sudan
Conflict/military coups	Armenia, Ethiopia, India, Myanmar, the Palestinian Territories, and Sudan
Elections	Niger, the Republic of Congo, Uganda, and Zambia
School exams	Ethiopia, India, Sudan, and Syria
Other (ongoing repression, communal violence, religious holidays, unknown)	Bangladesh, Belarus, Chad, China, Ethiopia, Iran, Nigeria, Russia, and Tajikistan

Some existing studies on Internet shutdowns try to estimate the probability of an Internet shutdown, associating various "risk" factors that are typically precursors to a shutdown (e.g., [13]). Country-specific studies look at the cost of shutdowns in India [7, 14], Myanmar [15], Belarus [8], and Pakistan [16]. More broadly, there is the thinking on reframing shutdowns not as one-off events or intermittent outages, but to explore various nuances of shutdowns in terms of their length, nature, and depth [17]. This is especially the case in various African countries, where there has been extensive work on the links between digital technology use and economic growth [18]. There is also extensive work by the Organization for Economic Cooperation and Development (OECD) in their background report on the economic and social benefits of Internet openness [19]. Given that the Internet has become pervasive in societies around the world, its benefits (and therefore costs) reach diverse sectors such as health, education, trade, entrepreneurship, and the arts. The World Bank's World Development Report 2021 focused on data for development and contained a description of how disruptions to the Internet affect citizens' trust in the Internet as well as have economic consequences (e.g., in Myanmar, where the economic impacts of Shutdowns are studied in detail) [4]. Finally, although not directly testing the impact of Internet shutdowns, work by Chiplunkar et al. [20] suggests that there are significant positive effects of 3G mobile Internet technology on employment growth in developing countries. They suggest a reshuffling of labor activities on the basis of access to 3G services, which could affect men and women differently.

2.2 Measuring the costs of Internet shutdowns

There are a couple of tools that currently provide rough estimates for the cost of Internet shutdowns as described previously. For example, the NetBlocks Cost of Shutdown Tool (COST)[21] uses a modified formula from West et al. [5] (Brookings Methodology) and the Collaboration on International ICT Policy for East and Southern Africa (CIPESA) [22] to compute costs per day for Internet shutdowns by country.

Multiple reports have made use of the above tools and methodologies to calculate the cost of shutdown. The Brookings Institute (an American Research Group) calculated that shutdowns in 19 countries had cost at least $2.4 billion in gross domestic product globally in 2016 [5]. The World Bank recently calculated Internet shutdowns in Myanmar alone had cost nearly $2.8 billion between February and December 2021, reversing economic progress made over the previous decade. Over a third of the companies surveyed for that report indicated that limited Internet access had severely constrained their business operations. For the Sub-Saharan Africa (SSA) region, the Collaboration on International ICT Policy for East and Southern Africa (CIPESA) [22], developed a framework to estimate the impact of disruptions in this region, and applied it to select countries in Africa that had experienced shutdowns between 2015 and 2017. Based on that report, the highest daily cost was estimated to be in Kenya, at US$6.3 million, followed by Ethiopia at US$3.5 million, and DR Congo at US$1.9 million. The highest estimated daily total cost due to app disruptions was in Ethiopia at US$874,935, followed by DR Congo at US$484,228 and Kenya at US$440,619. Also according to the report, Internet shutdowns in SSA cost the region up to US$237 million between 2015 and 2017.

However, while the Brookings and CIPESA methods have proven to be quite useful in providing approximations, they may be overestimating the economic impacts of Internet shutdowns for two reasons. First, it is unclear[3] if these current methods account for other factors that could be simultaneously explaining changes in economic output. It is important to use concomitant economy-level indicators that could explain changes in output, typically socio-demographic controls. Second, they do not incorporate government capacity to shutdown the Internet nor show that past occurrences of Internet shutdowns could affect future shutdown incidents. In contrast, our method uses a rich variety of datasets to explain the likelihood of a shutdown and predict its economic consequences. Secondly, the data for COST was last updated in 2021, and may not fully account for past years' data. The proposed estimator in this paper uses data from 2019 to 2022 on a wide set of indicators to use historical data on shutdowns to explain impacts, which can also potentially be used to forecast how likely a shutdown event will be in that country. Our econometric framework outlines precisely the estimating equations as well as the measured variables that are used in estimating the impact of shutdowns. Existing work on the impacts of the Internet does not extensively exploit the fact that Internet shutdowns can have adverse impacts on the local economy in terms of output, employment, and investments. There is a lack of rigorous economic analysis of the impacts of shutdowns that can be more broadly applied to specific regions that account for variations in the intensity (i.e., duration) of shutdowns, as well as go beyond providing broad GDP cost estimates which may not capture economic impacts fully. Our paper aims to bridge this gap by providing an econometric estimate of the impact of Internet shutdowns on GDP, employment, and foreign direct investment using panel data on nearly 100 countries. To the best of our knowledge, this analysis is the first of its kind to use wide-scale data on Internet shutdowns to explore economic impacts that vary by type of shutdown as well as on multiple outcomes beyond GDP.

3 DATA

In this section, we provide details on the different *publicly available* datasets, which we use in our methodology to calculate the economic impact of an Internet shutdown. Using open datasets makes our methodology fully reproducible. The data used in this analysis are detailed below:

(1) **Shutdowns data**: Detailed event-level data is available from the Internet Society Pulse Platform (ISOC Pulse, henceforth) starting 2019. The data only contains information on shutdowns by governments and classifies shutdowns as either national or regional shutdowns or service blocking. For each shutdown event, it also documents the cause of the shutdown. The causes, however, are varied and cannot be coded consistently across countries and over time and hence are not used. We also use data from an expert survey by the Digital Society Project (DSP), part of the Varieties of Democracy (v-DEM) project to capture government capacity to impose an Internet shutdown in a particular country. We use the mean score across experts in a country for a particular year, with lower scores meaning less government capacity to implement a partial or full Internet shutdown [23].

[3]Furthermore, there is also a perceived lack of transparency as there is no clear methodology document that outlines precisely *how* the Brookings and CIPESA methods have been implemented in the Netblocks COST tool.

(2) **Protests and civil unrest**:The Armed Conflict Location & Event Data Project (ACLED[4]) provides detailed event-level data on various events since 2016 [24]. Each event is classified as belonging to one of five types: (a) battles; (b) protests; (c) riots; (d) strategic developments; or (e) Violence against civilians. It also logs the start and end dates for these events, and provides details of who the involved parties were, and if there were any fatalities associated with the event.
(3) **Elections**: This data comes from the Constituency-Level Elections Archive (CLEA[5]) maintained by Yale University [25]. We use data from elections to the lower chambers, that is available for more than 150 countries at the month-year level since 1960.
(4) **Economic indicators data**: We use data on economic indicators (GDP per capita in USD purchasing-power-parity terms, constant prices of 2011), employment (International Labor Organization or ILO estimates, separately for male and female), Inflation (percentage), Foreign Direct Investment (FDI, as a percentage of GDP as well as net inflows) from the World Bank. In addition to these economic indicators, there are other factors that could explain country-specific economic outcomes such as age dependency ratio (percentage of working 18-65 years old to total population), fraction of population residing in urban areas, and percentage of the labor force with basic education. There are additional variables related to the characteristics of the Internet (number of secure Internet servers per million, number of fixed broadband users, number of mobile Internet users) that we use for heterogeneity analyses.
(5) **Internet Resilience**: This data comes at the country level for 2021 for a range of countries, based on the Internet Society's Internet Resilience Index[6] (IRI). The index is built around four sub-dimensions (or pillars) related to infrastructure, performance, security, and market readiness. Specifically, we use raw data on the indicators related to network coverage (defined by the number of fixed broadband users per million), market concentration, and the Gini coefficient of AS hegemony [26] for our heterogeneity analyses. Market concentration is defined using a Herfindahl-Hirschman Index (HHI) from APNIC ASPOP[7] statistics on market share by AS and by country. The HHI ranges between 0 and 10,000, where scores closer to 0 imply low market concentration (i.e., a competitive market) and scores closer to 10,000 imply a monopoly or oligopoly. AS Hegemony is a measure of network centralization and dependency. This is a score assigned to a network to measure its centrality as observed by BGP monitors [8]. The Gini coefficient of AS hegemony ranges between 0 and 1 and can be interpreted as the average fraction of paths crossing a node. The higher the AS Hegemony score, the higher the dependency on that specific network. For more details on the data sources and computation of these measures, we refer the reader to the Internet Society's Internet Resilience Index methodology [27].

In Table 2, we report the datasets used, the variables extracted from these datasets, and how they are defined for the analysis.

The summary statistics are reported in Table 3. These report t-tests by whether or not the country experienced an Internet shutdown in that year, and the values are averaged over years. The statistical significance values suggest that countries that experienced an Internet shutdown differ systematically from those that did not experience an Internet shutdown. For example, in terms of conflict events, there is a higher incidence of protests and riots in countries where there was at least one shutdown. Shutdowns are also more common in countries that have lower per capita incomes on average (USD 7500 approx. in countries with a shutdown, relative to USD

[4]https://acleddata.com/
[5]https://electiondataarchive.org/
[6]https://pulse.internetsociety.org/resilience
[7]https://stats.labs.apnic.net/cgi-bin/aspop
[8]A BGP monitor collects data on Internet routes received by the network where the monitor is placed. These monitors are deployed in many networks around the world and they help collect routing information which are then made public by projects such RIPE RIS and Route Views.

Table 2. List of variables, their definitions and the associated transformation technique.

Dataset	Variable	Definition
ISOC Pulse	Shutdown	A dummy variable that takes the value of 1 if there was a shutdown in that month-year in the country, and zero otherwise.
	Duration	A continuous variable that counts the number of days from the start of the shutdown to the end date for each country.
	Shutdown type	A categorical variable was recorded from the original dataset to have only two categories. Takes a value of 1 if there was a shutdown (any type), and 0 otherwise
ACLED	Conflict type	A categorical variable that takes a value of 1 for Battles; 2 for Protests; 3 for Riots; 4 for Strategic developments; and 5 for Violence against civilians. 1 is taken as the base category for each event and event type dummies are used.
	Fatalities	Number of fatalities (if any) associated with the event.
CLEA	Election	A dummy variable that takes the value of 1 if there was an election in the lower chamber for that country in that month-year.
World Bank World Development Indicators (WDI)	GDP per capita	Measured using the GDP per capita at current prices in purchasing power parity (PPP) terms;
	GDP	Measured using the GDP at current prices in purchasing power parity (PPP) terms;
	Fixed broadband coverage	Fixed broadband users per 100, converted to a categorical variable with four quartiles of fixed broadband coverage in each country.
	Female unemployment	Unemployment, female (% of female labor force) (modeled ILO estimate)
	Male unemployment	Unemployment, male (% of male labor force) (modeled ILO estimate)
	Total unemployment	Unemployment, total (% of total labor force) (modeled ILO estimate)
	Labor force education	Labor force with basic education (% of total working-age population with basic education);
	Dependency ratio	Age dependency ratio (% of working-age population);
	Urbanization	Urban population (% of total population);
	FDI (% of GDP)	Measured using net inflows of Foreign Direct Investment (as a % of GDP);
	Inflation GDP-linked	Measured using Inflation: GDP-linked deflator (annual %)
Internet Resilience Index	AS Hegemony	A categorical variable that takes a value of 1 for countries with less than the median score on AS Hegemony Gini coefficient; and 2 for countries with a greater than median score
	Market concentration	A categorical variable that takes a value of 1 for countries with less than the median score on market concentration; and 2 for countries with a greater than median score

23300 approx. in countries where there was no shutdown). However, the unemployment rate is slightly lower in countries with a shutdown on average. Countries that have experienced Internet shutdowns also differ in terms of what the Internet looks like: there are fewer service providers on average relative to those countries that did not experience a shutdown; and paradoxically enough, far fewer Internet users (in terms of mobile subscribers as well as fixed broadband users) on average. Given the ambiguity over these differences, it is important to account for these factors in explaining the likelihood of an Internet shutdown in our estimations.

Table 3. Summary statistics by Internet shutdown

	No shutdown		**At least one shutdown**			**Full Sample**		
	N	Mean	N	Mean	t-stat	Mean	Min	Max
Conflict events								
Battles	624109	0.16	67134	0.10	48.20	0.16	0	1
Protests	624109	0.59	67134	0.69	-51.98	0.60	0	1
Riots	624109	0.07	67134	0.10	-28.44	0.07	0	1
Strategic developments	624109	0.06	67134	0.05	20.04	0.06	0	1
Violence against civilians	624109	0.12	67134	0.06	52.96	0.11	0	1
Violence-related fatalities	624109	0.51	67134	0.32	14.16	0.49	0	600
Proportion with election	624109	0.01	67134	0.00	20.66	0.01	0	1
Socio-economic indicators								
GDP per capita US PPP current prices	471641	23301.22	54040	7497.37	466.38	21676.59	771.10	134753.80
Inflation (%) delfated	483146	9.36	57126	7.79	19.13	9.19	-26.30	558.56
FDI share of GDP	266130	1.96	41027	1.68	22.77	1.92	-34.21	163.04
Female unemployment rate (ILO modeled estimate)	514093	10.78	60379	8.47	65.55	10.54	0.18	41.15
Male unemployment rate (ILO modeled estimate)	514093	7.90	60379	7.11	55.73	7.81	0.07	31.84
Total unemployment rate (ILO modeled estimate)	514093	8.60	60379	7.28	80.07	8.46	0.10	33.56
Age dependency ratio	514151	57.46	60378	53.18	98.78	57.01	17.81	110.26
Urban population share	514271	65.00	60378	40.66	389.65	62.44	13.37	100.00
% of Labor force with basic education	294786	44.36	36136	49.55	-132.17	44.93	12.62	91.79
Internet-related characteristics								
AS Hegemony	624109	51.01	67134	60.37	-329.61	51.92	0.00	69.06
Market concentration score	622989	7.35	67134	8.00	-256.29	7.41	5.53	9.19
Proportion with past shutdown	624109	0.05	67134	0.66	-331.78	0.11	0.00	1.00
Fixed broadband users (per million)	266520	17.65	44562	3.85	342.59	15.67	0.00	62.36
Mobile internet subscribers (per million)	284243	103.84	45031	85.70	184.29	101.36	16.57	200.63
Internet servers (per million)	284227	18726.86	45031	660.16	227.78	16255.96	0.08	277081.80
Democracy indicators								
Freedom House Index score	355984	45.12	53029	38.72	108.59	44.24	0.00	82.00
Fragile States Index (without economic indicators)	616832	54.69	67134	63.62	-191.76	55.56	9.70	89.80
Shutdown capacity (V-Dem index)	515204	0.34	60379	1.94	-366.74	0.50	-5.33	6.38

Figure 2 shows the length of shutdowns by event type using ACLED classification for 2019. Events coded as involving violence against civilians were associated with longer Internet shutdowns on average in 2019.

4 METHODS

4.1 Methodological Issues

One of the main challenges in examining the impact of Internet shutdowns on broad economic indicators lies in accounting adequately for other factors that explain economic output. A second econometric issue here is common in similar research problems, which is that of identification. In principle, it is challenging to disentangle

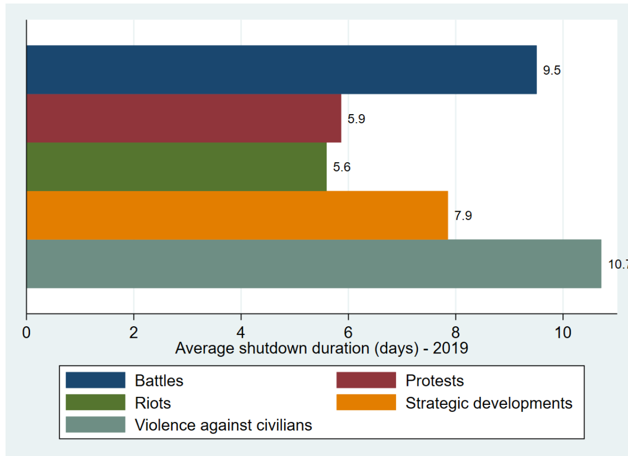

Fig. 2. Duration of shutdowns (2019) by event type (days)

the chain of causality from shutdowns to economic impacts without acknowledging potentially the reverse causality that may be present (e.g., are countries with specific economic or Internet-related characteristics more likely to experience shutdowns?). There are many ways to overcome this challenge econometrically (since in an ideal world, Internet shutdowns are not imposed randomly and are often subject to some explanatory factors), including using parametric (instrumental variables regression) and non-parametric (propensity score matching) methods. In this paper, we use a 2-stage instrumental variables (IV) strategy that hinges on several assumptions about the links between Internet shutdowns, economic outcomes, and factors that affect the likelihood of Internet shutdowns (or shutdown risk).

First, it is necessary to examine past work that associates some factors with the likelihood of observing Internet shutdowns. As per the Freedom House 2022 Report, government policies related to Internet censorship or control are strongly correlated with Internet shutdowns [28]. This suggests that the more control a government exerts over the Internet, the more likely it is that there will be an Internet shutdown. Next, shutdowns often coincide with political instability or conflict in the country [9], suggesting that governments may "flip the killswitch" on the Internet to quell violent protests, terrorist activities, or other citizen activism that it deems harmful [6]. Governments may thus shut down the Internet in order to control the flow of information and suppress dissent. In times of political crisis, governments may shut down the Internet to prevent the organization of protests or to limit access to information about the crisis.

Finally, there is also some evidence to suggest that Internet censorship (e.g., service blocking) may be part of a careful strategy to limit access to information about economic conditions or to prevent the spread of information that could lead to panic or instability within the country [16]. Governments may shut down the Internet in order to prevent the spread of information that could incite social unrest or to prevent the organization of protests, which is linked to instability in general. Though not a common occurrence, governments can also justify shutting down the Internet to prevent the spread of malware or other cyber-terrorist attacks [29].

It is worth noting that the specific factors that contribute to the likelihood of an Internet shutdown in a country can vary depending on the country's specific political, economic, and social context.[9] Additionally, many countries have laws and regulations that give the government the power to shut down the Internet, either under

[9]It is important to acknowledge here that in the absence of a theoretical framework on *how* Internet shutdowns can affect economic outcomes, we rely on a range of past work and assumptions on the channels through which these impacts might be observed. Thus, a

certain circumstances or at any time [10] The validity of our econometric specification hinges on the fact that these factors that explain shutdown risk do not also directly explain broad economic outcomes such as GDP or employment. For this to hold true, we need to have a unique identifier that explains Internet shutdowns but does not have a direct link with economic outcomes. In the case of our model, we argue that there are two candidate variables: (a) elections: there is some evidence that suggests the absence of a "political business cycle" - i.e. there is no association between election quarters and economic growth as well as employment in OECD countries [24]. Thus, it is plausible that election cycles involve political uncertainty and could enable Internet shutdowns, but may not directly affect economic outcomes, rendering the exclusion restriction as potentially holding. (b) shutdown capacity: we use data from the expert survey of the Digital Society Project (DSP) under the Varieties of Democracy (V-DEM) Institute dataset [23, 30] from the corresponding years that has extensive coded data on democratic indicators. The specific question that we use is *"Independent of whether it actually does so in practice, does the government have the technical capacity to actively shutdown domestic access to the Internet if it decided to?"*, with a response going from 0 (it lacks the capacity to do so) to 4 (it has the capacity to shutdown all, or almost all, domestic access to the Internet). We use the averaged version of this variable, with a higher value indicating expert opinion (aggregated) that the government indeed has the capacity to implement an Internet shutdown. Thus, to the extent that elections and shutdown capacity uniquely identify the shutdown risk, the two-stage model can be estimated, and the validity of the identification strategy is tested using a range of diagnostic statistics [11].

4.2 Predicting Internet Shutdowns (First Stage)

This subsection lays out the econometric specifications. Specifically, the first-stage equation predicts Internet shutdowns using previous shutdowns, government shutdown capacity, conflict events, and elections is as below:

$$\begin{aligned} Shutdown_{it} &= \alpha + \omega Shutdown_{it-1} + \tau ShutdownCapacity_{it} \\ &+ \beta_1 Conflicts_{it} + \beta_2 Election_{it} + \beta_3 Country_{it} + \epsilon_{it} \end{aligned} \tag{1}$$

Where, $Shutdown_{it}$ is the outcome variable that is a dummy variable (whether or not a shutdown took place) in country i at year t. It is regressed on the lagged indicator of if there was an Internet shutdown in the current (calendar) year. $ShutdownCapacity_{it}$ is the variable that measures expert opinion related to the capacity of the government to shut down the Internet in country i at year t. $Conflicts_{it}$ is a vector of events prior to the shutdown (riots, protests, exams, etc.); $Election_{it}$ is a dummy variable that takes a value of 1 if there is an election at time period t in country i, and zero otherwise; $Country_{it}$ is a vector of country-level Internet characteristics (e.g., the market concentration index of Internet providers); $epsilon_{it}$ is the error term. Since there are multiple outcome variables, there will be separate estimations for each count as well as for each dummy variable.

An alternative duration model is also specified that uses a count variable (duration of shutdown in days) conditioned on observing a shutdown. Since duration is counted only for those country-months where a shutdown was observed, estimation by ordinary least squares or other linear methods will be biased. We, therefore, use a censored regression approach (where the dependent variable of duration is censored at zero) with the same

limitation of some of the below empirical frameworks is that they are born as "behavioral" equations, and do not necessarily align with economic theory.

[10] It is also worth noting here that this paper does not address Internet shutdowns that were not imposed by governments, i.e., those that may be due to climate shocks or similar events which cause cable cuts or destroy Internet infrastructure, leading to outages. Although these types of shutdowns are less common than government-imposed ones, assessing their economic impacts may not face the same econometric challenges (e.g., endogeneity, since climate shocks are exogenous) as in the current model. We leave this for future work.

[11] Note that it is possible to use a range of alternative econometric approaches such as event-study frameworks [31] or propensity-score matching methods [32]. We use these models to check for robustness of our estimates and outline why one might favor two-stage models given the context of our estimation.

explanatory variables as in equation 1. The resulting prediction is then used in the second stage for estimating the impact of one additional day of Internet shutdown (when a shutdown is observed).

4.3 Shutdowns and Economic Outcomes (Second Stage)

The predicted value of shutdowns (either duration or probability) is then used to estimate their impact on a range of economic outcomes with additional country-level covariates that reflect other factors that could also be associated with the economic and social outcomes. The second stage is given by:

$$Y_{it} = \gamma + \delta_1 Shut\hat{d}own_{it} + \delta_2 Country_{it} + \eta_{it} \tag{2}$$

Where, Y_{it} is the outcome of interest, e.g., log of GDP per capita, log of employment levels (or employment rates), and log of net foreign direct investment (FDI) inflows. $Shut\hat{d}own_{it}$ is the predicted likelihood of shutdown taking place or the (predicted) duration of shutdown events in that country in a particular year from the first stage. $Country_{it}$ is a set of overlapping country-level covariates that are typically associated with economic outcomes. We consider inflation, the age dependency ratio, the percentage of the labor force with basic education, and the fraction of the population residing in urban areas.

These variables have been chosen on the basis of maximizing the number of observations per country (i.e., data availability), as well as past work that links these variables with economic outcomes [33, 34]. Since these are potentially endogenous to Internet shutdowns occurrence themselves (as well as economic outcomes), we deploy them in heterogeneous impacts analysis. These variables (measuring Internet resilience or market characteristics) are dichotomized for the analysis.

Finally, it is important to note that the years included in the data overlap with the COVID-19 pandemic (2019-2022). Although our model is estimated with country and time-fixed effects to account for any unobserved country-level variation or over time, including two-way FEs can help account for COVID-related impacts on the economy. In tests of the model with two-way FEs, many covariates drop out of the equation due to collinearity. Instead, we estimate a version of this model including the natural logarithm of new cases per million at a country-month level to account specifically for COVID-related impacts in the smaller sample of 2019-2022.

The model was estimated using panel instrumental variable (IV) regression models with standard errors clustered at the country level.

5 RESULTS

5.1 Incidence of Internet shutdowns

The strongest predictor of a current (or future) Internet shutdown is the presence of a previous shutdown in the country. The presence of a previous history of shutdowns is associated with a 21.1 percentage point increase in the likelihood of a future shutdown. Essentially, one additional report of a riot translates to roughly a 3.4% increase in the likelihood of a shutdown in the sample of 92 countries. The other event types from ACLED data do not show any statistically significant association with the likelihood of an Internet shutdown, or shutdown risk. Figure 3 below shows the coefficient plot of the first-stage regression (with the likelihood of shutdowns predicted by ACLED events). The dotted indicates a zero effect or association between that event type and the likelihood of shutdown, and the horizontal whiskers show the 95% confidence intervals.

It is plausible that the risk of experiencing a shutdown in any given country is also subject to how easy or difficult it may be in practice for a government to impose a shutdown. This is captured by looking at the same risk factors but by varying dimensions of the Internet in these countries. Figure 4 shows that past shutdowns matter the most in countries where there are fewer mobile subscribers and fewer servers per million individuals (i.e., these are below the median). In contrast, the associations between conflict events and Internet shutdowns

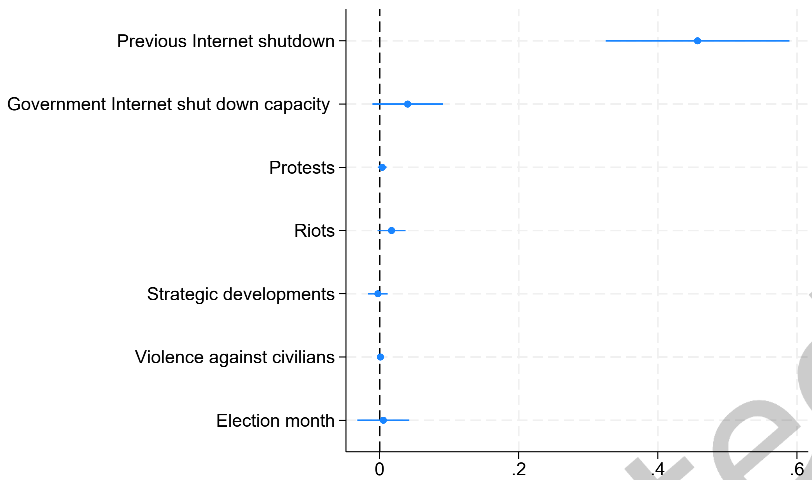

Fig. 3. Factors associated with Likelihood of Internet Shutdowns

Note: Plot depicts point estimates of coefficients and 95% confidence intervals from the first-stage of IV-regression of Internet shutdown incidence as described in equation 1.

are imprecisely estimated among subgroups, suggesting that conflicts do not necessarily have any interplay with Internet characteristics in determining the likelihood of Internet shutdowns.

Furthermore, how the Internet is organized in a particular country could also determine shutdown risk. For example, when there are relatively few networks and Internet services are largely provided by a single provider (or a handful), it is possible that it may affect the ease with which shutdowns can be imposed. For the heterogeneity analyses, we split our sample of countries where there is a high market concentration (median split) and high AS Hegemony (median split). In such countries, the Internet is likely to be controlled by a select few providers. Those below the median may have relatively more competitive markets and network decentralization. Below, Figure 5 shows how various factors are associated with shutdown risk contingent on these sets of countries. We find that the positive association between past shutdowns and future shutdowns is drawn from countries with high network centralization. The positive association between conflict events (e.g., riots and protests) is also driven by countries that have high network centralization as well as highly concentrated market of Internet service providers. This implies that there are specific dimensions of the Internet that matter for how much at-risk countries face in terms of Internet shutdowns around the world.

5.2 Duration of shutdowns

The results from the Tobit estimation of the duration of Internet shutdowns suggest a strong association between previous shutdowns and prolonged shutdown events. Furthermore, election-months were associated with shorter Internet shutdowns on average, whereas fatalities associated with conflict events were associated with longer Internet shutdowns on average. This suggests that the risk factors that predict Internet shutdown likelihood are also similarly associated with longer duration of shutdowns, conditioned on a shutdown being observed. The results are reported in the appendix (Table 6).

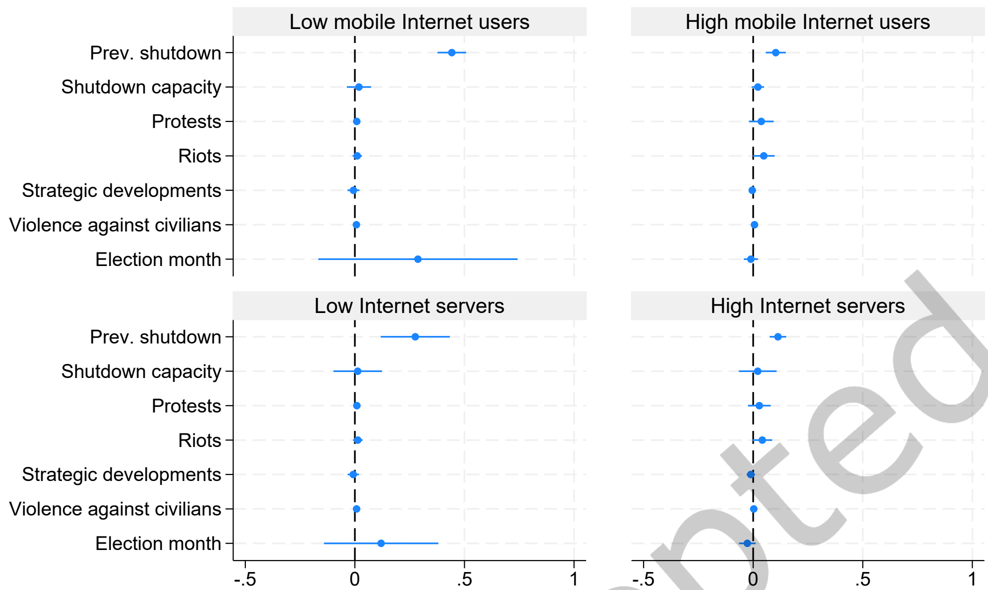

Fig. 4. Factors associated with Likelihood of Internet Shutdowns: Subscriber base and Internet servers

Note: Plot depicts point estimates of coefficients and 95% confidence intervals from four first-stage of IV-regressions of Internet shutdown incidence as described in equation 1, using a median split of a country's mobile subscriber base and number of Internet servers per million.

Finally, in Figure 6, we show the coefficient plots for each of these estimates and look at the male and female unemployment changes associated with shutdowns separately. These are described in more detail in the following table, and outline the association between the likelihood of Internet shutdowns and various economic outcomes. The main results of the impact of Internet shutdowns on economic outcomes are summarized in table 4. Since our dependent variable takes a value of 1 if the shutdown was observed in that country during that time period and zero otherwise, the results can be interpreted as changing the likelihood of an Internet shutdown. A 1% increase in the probability of an Internet shutdown is associated with a GDP per capita (in PPP terms) by about 15.6%. Our average prediction for shutdowns in the model is at 17%, so that roughly means that there were substantial losses to economic output that can be traced back to shutdowns using our model. These effects are not statistically significant for other economic outcomes such as Foreign Direct Investments (FDI), measured as a fraction of the GDP. Notably, shutdowns appear to have a strong, negative, and statistically significant association with employment. On average, a 1% increase in the shutdown risk is associated with a 2.2% increase in the unemployment rate in the country. These effects are driven largely by changes to male unemployment, given that in many countries in our sample, male labor force participation is much higher than female labor force participation. This impact of shutdowns reflects that the structure of the economy is important to take into account when deciphering their economic impacts.

The duration of economic impacts is depicted in Figure 7. We find that an additional day of Internet shutdown is primarily associated with a small decline in GDP (0.003 percentage points, statistically significant at the 10% level). In real terms, however, this approximately translates to every additional day of an Internet shutdown costs $86.58 per person on average. At the aggregate, an additional day of Internet shutdown was associated

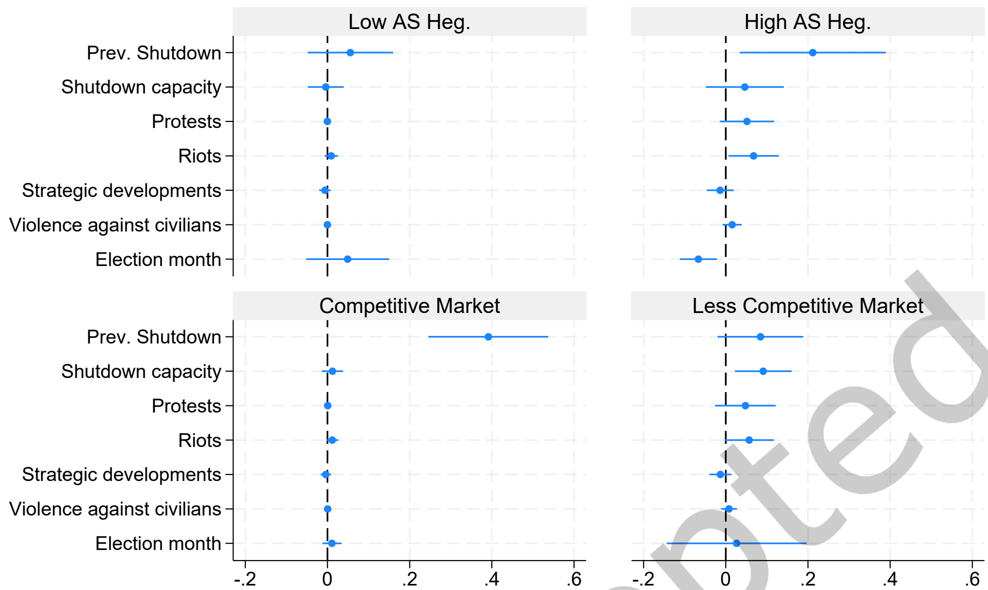

Fig. 5. Factors associated with Likelihood of Internet Shutdowns: Upstream provider diversity and Market structure

Note: Plot depicts point estimates of coefficients and 95% confidence intervals from four first-stage of IV-regressions of Internet shutdown incidence as described in equation 1, using a median split of the Gini coefficient of AS Hegemony, a measure of upstream provider diversity, and market concentration, measured by the HHI of Internet service providers in a country.

with a nearly $19.74bn loss in economic output annually between 2019 and 2021 on average. This suggests that although the countries that implement Internet shutdowns may be a few, their impacts are likely to have significant implications for the world's economic output as well. We show some rough approximations (see B in the appendix for details) of this using some recent Internet shutdowns in the appendix (Table 5). Due to a lack of other studies deriving similar figures, there are no directly comparable estimates. However, the Brookings estimate of an Internet shutdown in India for a day from COST yields an approximate loss of $1,431,042,434, compared to our estimate of $67,864,268. There is thus a 21 times difference in our estimates, suggesting that there is a wide spread of estimates available that may be overestimating the economic impacts of Internet shutdowns as well.

5.3 Robustness Checks

To examine the robustness of our specification, we undertook a series of tests to examine the validity of our main results. [12] We outline each of these below and compare the results with the findings presented above.

Our empirical strategy depends heavily on the validity of the instrumental-variables approach. An alternate approach in such cases could be to model Internet shutdowns as events in an event study framework where countries may move in and out of the "treatment" status (in this case experiencing an Internet shutdown), which

[12] We also included additional COVID-related variables to proxy for the pandemic and its associated economic impacts that may not be captured in the country and time FEs. The results on the impacts of Internet shutdowns on GDP per capita are similar, but the coefficient on Internet shutdowns was no longer statistically significant. The results on unemployment and FDI are similar as well.

can be incorporated using two-way fixed effects [31]. We adopt this approach in our data and find that the treatment effect is $-0.011(s.e. = 0.0192)$, suggesting that the overall economic impacts could indeed be negative, although they are imprecisely estimated using this approach.

A second approach we use to verify our findings involves the use of non-parametric methods such as propensity-score matching, or PSM [32]. In such a case, matching on observables relies largely on two assumptions of common support and overlap being satisfied. We adopt a 5-nearest-neighbor matching with our dataset and report the results only on the main outcome variable of GDP[13]. In the results on GDP, we find that Internet shutdowns were associated with an average treatment effect on the treated (ATT) of $-0.038(s.e. = 0.075)$, and the average treatment effect (ATE) was -0.924. Note that these are the estimates only for those observations that meet the assumption of common support and have overlap. Although we cannot control for other factors that could be associated with variations with GDP in PSM, we can infer that our negative association of Internet shutdowns on GDP holds across specifications.

Our analysis relies heavily on the validity of the identification of the Internet shutdowns equation, and these alternate approaches suggest that the negative association between Internet shutdowns and economic outcomes (particularly GDP) is not sensitive to the empirical specification used.

[13]We undertook additional matching procedures such as radius, kernel, and Mahalanobis matching and find qualitatively similar results but omit reporting them here in detail for all outcome variables as the procedures were computationally more onerous.

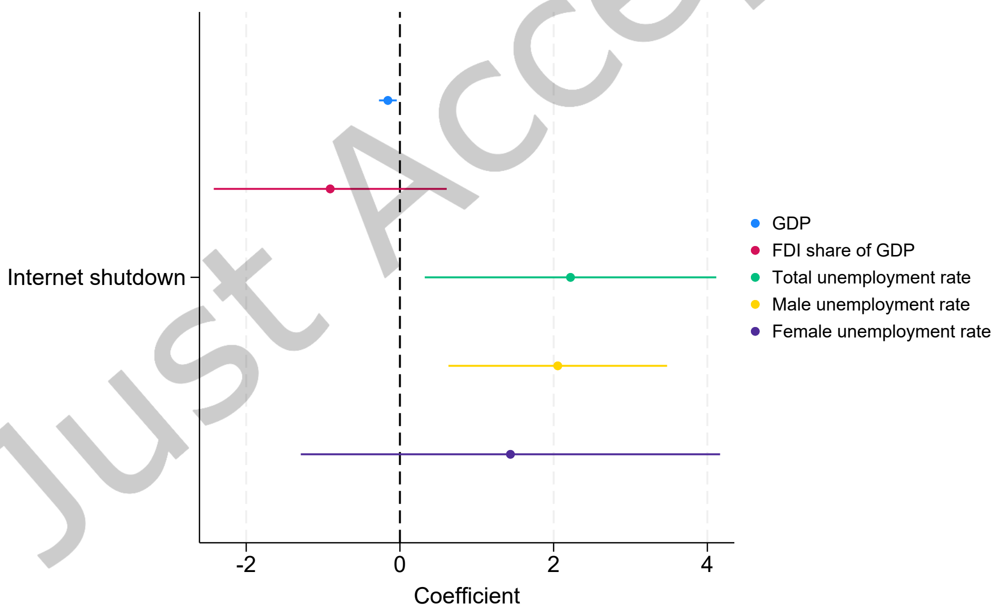

Fig. 6. Association of Internet shutdowns with different economic outcomes, coefficient plot with 95% confidence intervals

Note: Plot depicts point estimates of coefficients and 95% confidence intervals from the second-stage of the IV regression of Internet shutdown incidence as described in equation 2.

Table 4. Internet shutdowns and economic outcomes

	(1) ln (GDP)	(2) ln (FDI share of GDP)	(3) Total Unemp	(4) Male Unemp	(5) Female Unemp
Internet shutdown	-0.156***	-0.907	2.220**	2.054***	1.438
	(0.0583)	(0.761)	(0.955)	(0.716)	(1.374)
ln (GDP)		5.956	-8.049**	-11.49***	-0.0856
		(3.818)	(3.089)	(2.556)	(4.378)
First-stage F-stat	80.11***	2.55***	22.86***	22.86***	22.86***
Sanderson-Windmeijer (SW) first-stage chi-squared (underidentification)	1700.46***	51.6***	485.20***	485.20***	485.20***
Stock-Wright LM S statistic (weak instrument)	29.67*	23.14	24.94	25.35	28
Hansen J-statistic (overidentification)	23.75	9.75	17.52	20.63	19.49
Observations	312,675	192,820	312,675	312,675	312,675
R-squared	0.068	0.310	0.392	0.526	0.203

Note: Total unemployment is defined as % of total labor force (modeled ILO estimate); Female unemployment is defined as % of female labor force (modeled ILO estimate); and male unemployment is defined as % of male labor force (modeled ILO estimate). All estimates report coefficients from 2-stage IV regression, first-stage estimates are available in the appendix (Table 7).

6 CONCLUDING REMARKS

This analysis finds that there is a strong correlation between Internet shutdowns and economic outcomes using data between 2019 and 2021. We used a novel econometric and data-intensive approach to compute these associations as the economic costs of Internet shutdowns, using GDP as an outcome variable. We compute and present factors associated with a greater likelihood of observing Internet shutdowns, including past Internet shutdowns and conflict events.

Specifically, we find that a 1 percentage point increase in the likelihood of Internet shutdowns is associated with a 15.6 percentage point reduction in the GDP per capita of a country. Internet shutdowns are also associated with adverse changes in other economic outcomes such as increasing the unemployment rate marginally. In countries that experienced an Internet shutdown, we find that one additional day of an Internet shutdown was associated with a small decline in GDP (0.003 percentage points), which translates roughly to a nearly $20bn loss annually in global economic output.

Our findings, though the first to empirically investigate the factors associated with an Internet shutdown and trace their downstream correlation with economic outcomes, rely on certain assumptions and must be interpreted with caution. First, we are unable to provide causal estimates of the impact of Internet shutdowns. These are

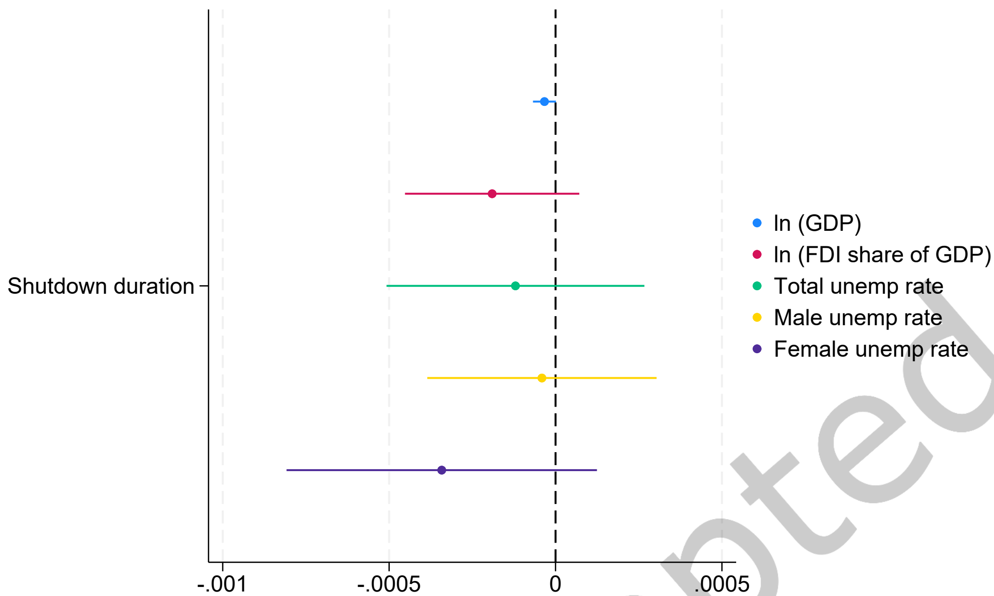

Fig. 7. Association between an additional day of Internet shutdown and economic outcomes, coefficient plot with 95% confidence intervals

correlations that provide varying degrees of precision on how economic outcomes evolve when there is an Internet shutdown. There could be various other factors that influence these economic outcomes which may not be fully accounted for in this model. One way to overcome this is to look at the literature on the impact of monetary policy shocks using dynamic stochastic general equilibrium (DSGE) models [35, 36]. This requires more careful construction of economic databases to correspond with the timing of Internet shutdowns and relies on its own set of assumptions about macroeconomic changes.

Second, our analysis is restricted by the frequency at which data on various outcome variables as well as covariates are available consistently. For example, one could use night light data as a proxy for economic activity to map at more granular levels changes that can be tracked back to Internet shutdowns. The major shortcoming of this approach is that other economic data (e.g., on covariates such as inflation) are typically unavailable at the same frequency, making attributing changes in light intensities to Internet shutdowns complicated. Causal inference is also challenging given the artifacts that crop up in night light data (e.g., natural disasters, fires, etc.) that could artificially increase or decrease light intensities in a particular region.

Thirdly, there is scope for future work to combine data on shutdowns, economic outcomes, and Internet speed data collected at higher frequencies by services such as Ookla. This can help gauge the changes in speed that can be traced back to Internet shutdowns and their impact on throughput (bandwidth) in turn can be examined in the context of local economic activity. In an ideal scenario, having data on economic outcomes before and after an Internet shutdown down to the level of the individual or household can help better examine the short-and-long-term impacts of shutdowns.

7 FUTURE WORK

In future work, we propose to combine theoretical motivations for our choice of factors associated with the likelihood of an Internet shutdown with a statistical approach. This statistical approach would rely on machine-learning models (such as random forests) to determine a set of factors that most strongly and robustly predict Internet shutdowns in a particular country. The validity and strength of such a model can be tested using out-of-sample predictions and assessing how closely the estimates of shutdown risk match up with actual shutdown patterns around the world.

Finally, we plan to extend the current econometric model to include climate-related Internet shutdowns and other types of shutdowns, as an additional method of exploring these problems. We intend to analyze available datasets regarding the econometric impact of non-governmental Internet outages as this might give further insight into these issues and help to disentangle the chain of causality. This entails developing a model of Shutdown risk as a function of non-government imposed events causing cable cuts or other infrastructural damages.

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A APPENDIX

B ILLUSTRATION OF REAL COSTS OF INTERNET SHUTDOWNS

We use the coefficient of duration of shutdown to simulate the associated net loss in GDP per additional day of shutdown. In Table 5, we illustrate for a select group of countries the scale of the associated loss in GDP (in PPP terms) over the period of 2019 to 2022. This is calculated by the following formula:

$$NetLoss_i = GDP_i \times PredDuration_i \times InternetUse_i \tag{3}$$

Where, $InternetUse_i$ is the percentage of individuals using the Internet, and $PredDuration_i$ is the coefficient derived from the estimation of predicted duration on GDP (-0.003). The resulting estimates can be used as a rough estimate of the losses associated with prolonging an Internet shutdown on economic productivity. This set of countries is used only for illustrative purposes, and in principle, this estimate can be extended to countries where there were no shutdowns as well. One should treat these estimates with caution as they are in no way causal, and also overweight the GDP of a country in its estimation (i.e., richer countries are overweighted in this estimation).

Table 5. Aggregate costs of additional day of shutdown for select countries (weighted by fraction of Internet users)

Country	**Net Loss (GDP PPP $) per additional day of Shutdown (in Millions USD)**	**Fraction of Internet Users (%)**
Belarus	372	86.9
Ecuador	292	70.7
Egypt	1733	71.9
Indonesia	3653	62.1
India	8025	43.0
Iran	2381	78.6
Mali	30	27.4
Myanmar	218	35.1
Pakistan	479	25.0
Palestine	62	74.6
Russia	8382	88.2
Turkiye	402	81.4
Tanzania	81	22.0

Table 6. Tobit estimates of duration of Internet shutdown

VARIABLES	(1) Duration of Internet shutdown
Previous shutdown	96.67***
	(32.08)
Government Internet shut down capacity	67.09**
	(29.06)
Protests	-2.789
	(28.78)
Riots	13.39
	(30.80)
Strategic developments	7.951
	(23.55)
Violence against civilians	-2.195
	(17.84)
Election month	-628.3***
	(177.5)
Fatalities	1.576**
	(0.648)
Constant	-475.8*
	(284.1)
Observations	405,900

Note: Results report coefficients of a censored regression using Tobit of equation 1. Additional month, year, and country fixed effects included. Standard errors clustered at the level of country. $***p < 0.01, **p < 0.05, *p < 0.1$..

Table 7. First-stage results of Internet Shutdown likelihood

VARIABLES	(1) Shutdown
Previous shutdown	0.457***
	(0.0066)
Government Internet shut down capacity	0.040
	(0.025)
Protests	0.004
	(0.003)
Riots	0.0171*
	(0.0101)
Strategic developments	-0.0026
	(0.007)
Violence against civilians	0.0011
	(0.002)
Election month	0.0053
	(0.0188)
Fatalities	0.001
	(0.0009)
Observations	312675
F-statistic	11.7***
R-squared	0.068

Note: Results report first-stage coefficients of regression using IV method of equation 1. Additional month, year, and country fixed effects included. Standard errors clustered at the level of country. $***p < 0.01$, $**p < 0.05$, $*p < 0.1$. Second stage results are reported in Table 4.