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ICT/Cyber benefits and costs: Reconciling competing perspectives on the current and future balance

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ABSTRACT

Information and communications technology (ICT)/cyber technologies become ever-more embedded in our economies and societies, bringing both benefits and risk-related costs. The balance between those benefits and costs, over time and across countries, remains poorly understood. This gives rise to conflicting narratives about the future of ICT: either (1) continued rapid benefit growth with new waves of ICT technology; or (2) increasing cyber-attack costs will come to swamp benefits.

We explore how the balance between benefits and costs might change at the global, country-grouping, and country-level out to 2030. Because the existing literature provides little foundation for integrated analysis, we did extensive conceptual research and data gathering from diverse sources. The benefits include the growth of the ICT sector itself, its contribution to broader productivity as a general purpose technology, and its benefits for consumers as value for price rises very significantly. The costs include security spending, the impact of adverse cyber events, and opportunity foregone if the technology is underutilized.

We extended International Futures (IFs), an existing multi-issue, multi-country, long-term forecasting system with formulations driving ICT/cyber advance and impact. In Base Case analysis we found that, while annual costs related to cyber-attacks and cyber-security spending do come to outweigh the annual incremental economic benefits from ICT use in high-income countries, over time the compounding nature of the benefits versus the more additive nature of the costs means that the cumulative benefits will outstrip the cumulative costs by tens of trillions of dollars over even medium-term forecast horizons. For lower-income and middle-income countries both annual and cumulative analyses suggest that benefits will continue to outweigh costs. On a global basis the cumulative net benefits could exceed $100 trillion through 2030. Four scenarios with significantly different assumptions about technological development and the unfolding of adverse events changed the total values of benefits and risk-related costs, but not the overall conclusion.

1. Introduction

The media shower us with two competing narratives regarding information and communications technologies (ICT). They tout the benefits of the latest and greatest technological developments and speculate often breathlessly about how much greater those benefits will be in the future, even while maintaining a steady drumbeat of dire warnings concerning the threats that cyber-activism (hacktivism), cybercrime, cyber-espionage, and even cyberwar and cyber-terrorism pose to economies and governments around the world. The more analytical literature on the economic benefits and costs of ICT technologies reinforces this clash of narratives, with some analysts seeing ICT continuing to spur significant economic growth for decades to come, while others argue that the benefits have largely been reaped and that the cost of maintaining adequate cybersecurity and the damage from cyber-attacks is becoming so great that the technologies will become a liability and a net drag on growth. But which is it? What is the balance between the benefits and costs of ICT, and how might that balance vary over time and across countries? With ICT technologies becoming ever-more ubiquitous, it is important that we reconcile these two seemingly opposed narratives.

In this paper, we explore the economic benefits and costs of ICT technologies and investigate how the balance between them may change out to 2030 for 186 developed and developing countries around the world. In doing so, we have: (1) constructed typologies of benefits and costs of ICT and identified the primary drivers of change in each element; (2) gathered a wide-range of data on ICT use and pervasiveness; (3) drawn insights from many individual studies of those elements and (4) augmented the International Futures (IFs) model—a dynamic, highly-integrated system for forecasting long-term human development futures across many

Abbreviations: IFs, International Futures; ICT, information communications technologies.

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issue areas—to enable the forecasting of possible trajectories of ICT pervasiveness, benefits, risks, and costs.[2] We present our findings in terms of four alternative scenarios built from some of the key uncertainties surrounding the technologies.[3] Note that we use information and communications technology (ICT) and cyber interchangeably in this study.

Our typology, built upon recent literature, breaks both economic benefits and costs of the technologies into three major categories[4]:

- Economic benefits of ICT:
  - o Direct contributions to growth from increases in the size of the ICT-producing sector
  - o Indirect contributions to growth from enhanced production and productivity across the wider economy thanks to the progressive embedding of ICT into the economy's capital stock
  - o Consumer-captured surpluses thanks to steadily and rapidly decreasing prices or improved capacity and quality offered at the same price as old systems

- Economic costs of ICT (borne by households, firms and other organizations, and governments):
  - o The spending required to defend against adverse cyber events (cybersecurity)
  - o The cost of adverse cyber events—broken down by actor-threat and target
  - o Opportunity costs—potential economic benefits that remain unrealized by forgoing the use of ICT out of fear of cyber-attacks or for other reasons such as social control

ICT's greatest economic benefit has been its contribution to productivity in the economy at large. Estimates of its past contribution range from 20 to 30% of annual economic growth, or depending on the country about 0.6 to 1.5 percentage points of absolute contribution. Many studies, however, focus more narrowly on the economic impact of individual technologies, like broadband, rather than ICT as a whole (Atkinson and Stewart, 2013; Czernich et al., 2011). Broadband, of course, is only a recent entry in a series of technology waves. Today's latest wave, cloud services, build on a foundation of broadband networks, while, already, several other future waves are visible, including the internet of everything and artificial intelligence (see MGI, 2013). Such waves complicate the analysis and forecasting of ICT's economic impacts, leading some analysts to point to saturation (Gordon, 2012, 2014; Cowen, 2011; Theil, 2011) with respect to annual economic impacts and others to anticipate an acceleration (MGI, 2013; Oulton, 2012; Kurzweil, 2006).

Our analysis of the costs of ICT reinforces a wider perception held in both the literature and the media: the annual costs from adverse cyber events and the cybersecurity spending to combat them has been increasing over time as a share of GDP. Estimates are that direct cybersecurity spending by firms worldwide has grown by roughly 8% per year over the last several years, reaching 0.1% of global GDP in 2015 (Gartner, Inc., 2014). Governments are also increasingly becoming more security conscious, with the US government's cybersecurity spending estimated at $13.3 billion in 2015, up from $8.6 billion in 2012 (Smith, 2011). The economic costs of adverse events are especially difficult estimate. In 2014, the cost of cybercrime and cyber-espionage, combined, ranged from an estimated 0.1% or less of GDP in Japan to 1.6% of GDP in Germany (CSIS, 2014).

The above discussion suggests that the two greatest uncertainties surrounding future ICT benefits and costs are (1) the unfolding of the technologies themselves, and therefore the potential extent of their impact on growth, and (2) the cost of adverse cyber events, especially around cyberwar and cyber-terrorism. These will shape the scenario analysis.

It could be that the benefits of ICT will trend downward as impact from the current wave of technologies saturates. It could also be that ICT is so closely linked to human knowledge expansion that ICT could follow the path of other general-purpose technologies (GPTs) like electricity. It could even set up a positive feedback loop generating exponential advances, moving us to an impending singularity with respect to artificial intelligence (Kurzweil, 2006). Nor does the debate over trends in adverse event costs help us greatly narrow the range of possible futures—while one side argues that offense will always have an advantage, causing costs and cybersecurity spending to soar with increasing ICT pervasiveness (Mandiant, 2013), other analyses like that of Microsoft's (Burt et al., 2014) around malware suggest that defensive capabilities are increasingly winning the battle.

This paper thus, while offering an admittedly imprecise understanding of the relative benefits and costs of ICT, attempts to fill in the gaps in the existing literature by (1) building an exhaustive typology of the different benefits and costs; (b) assessing contemporary and future monetary and economic values of individual and total benefits and costs; (3) encompassing a wide range of ICT types; and (4) exploring ICT futures in countries at all levels of development. We first delve into the conceptual, data, and formulation issues underlying our efforts to produce a quantitative model of ICT benefits and costs. We then turn to our analysis and forecasting across four scenarios designed to explore the major uncertainties of ICT futures.

2. Materials and methods: ICT and its benefits and costs

In order to analyze the competing benefit and cost narratives for ICT, four steps are necessary. First, in this section we must discuss the pattern(s) of likely advance in ICT. Second, also in this section, we must systematize the benefit and cost narratives by conceptually and empirically elaborating our typologies of benefits and costs. Third, in the next section we must represent both ICT advance and its benefits and costs in IFs. Finally, we must use the augmented IFs system for Base Case and scenario analysis.

2.1. The future advance (and impact) of ICT

Briefly stated, the different schools of thought regarding ICT's advance (and therefore its lasting role in driving productivity and growth) are: (1) the Pessimist school, which views major gains from ICT as a thing of the past; (2) the Optimist school, which believes that the gains are likely to continue, and even grow significantly, as new technologies arrive; and (3) a variation or extension of the Optimist school, that ICT should be regarded as a general-purpose technology (GPT) with especially wide and long-lasting economic impacts, like the steam engine and electricity before it.

According to the Pessimist school, earlier technologies like electricity, sanitation, and the automobile already claimed most of the low-hanging productivity fruit—i.e. they provided lasting productivity gains that cannot be replicated by existing or future technological innovations (Gordon, 2012, 2014; Cowen, 2011; Theil, 2011). For pessimists,

[2] The IFs model is housed at the Pardee Center for International Futures at the University of Denver and is available for research and further development without cost, at www.pardee.du.edu.

[3] This paper is a distillation of work done in a larger project on systemic cyber risks commissioned by the Zurich Insurance Group and in partnership with the Atlantic Council's Brent Scowcroft Center for International Security. We would like to thank Zurich for its support. The final report released to the public is at http://www.atlanticcouncil.org/cyberrisks/. An extended report is at http://pardee.du.edu/sites/default/files/Cyber%20Risk%20Pardee%20Extended%20Report..pdf.

[4] We recognize there are a host of benefits and costs to ICT/cyber beyond those directly related to economic growth, from the societal benefits of keeping in touch with friends and staying up to date with the latest YouTube sensations to costs like the loss of privacy and cyber-bullying. The largely economic focus of this paper should not signal insensitivity to the importance of these other benefits and costs.

today's ICT innovations and all foreseeable innovations represent refinements of earlier technologies and thus are likely to provide only marginal additional benefits. This diminution of returns is part of their explanation for why the average annual rate of productivity growth (in terms of output per hour) in the United States has been markedly lower over the last 40 years (1.59%) than in the 81 years prior (2.35%) (Gordon, 2014: 21; see also Gordon, 2012).

At the heart of the Pessimist argument is the notion that the rate of innovation is slowing down. Byrne et al. (2013: 22) initially found support for the Pessimist school. They found that ICT's contribution to labor productivity in the US was significantly lower during 2004–2012 (0.64 percentage points) than from 1995–2004 (0.77 percentage points). But they also pointed out that there tends to be a time-lag in productivity gains from new technologies—while PCs first arrived in the 1980s, the productivity gains attributed to them only became visible in the 1990s. Thus the gains from the recent transition to post-PC technologies like mobile broadband equipped smartphones and tablets may be yet to come. The McKinsey Global Institute (MGI) (2013), Cardona et al. (2013), and Starr (2014) similarly found a lag between initial deployment and economic impact, as it takes time for the technologies to reach critical mass and for firms (and society) to reorganize to take full advantage of them.

The lag between initial deployment and measurable productivity effects obviously support the Optimist school of thought—that we are still in an early phase of ICT's economic impact. Oulton (2012: 1723) found that not only did ICT investment in the US reach levels post 2004 that were significantly higher than during the Dot.com boom, but that productivity gains remained rapid even during the subsequent bust and recession. A 2013 study by MGI (see also MGI, 2015) examined the potential economic value by 2025 of 12 "up and coming" disruptive technologies—those likely to disrupt current economic patterns.[5] The spread of mobile internet technologies, for example, could generate some $3.7 trillion to $10.8 trillion dollars for the global economy annually by 2025 (MGI, 2013: 34)—suggesting that by 2025, some 1.9 to 4.2% of the world's GDP could come from mobile internet technologies.[6] For cloud computing, the estimated economic impact in 2025 could range from $1.7 to $6.2 trillion dollars. A useful mental model may be of sub-waves within the long wave of ICT transformation, each of which leave their mark on economic growth even as they blend into each other to a significant degree.

Building on the Optimist perspective, many researchers have come to see ICT as bearing the hallmarks of a general-purpose technology (GPT). GPTs have three primary characteristics: (1) applicability across a wide range of uses (pervasiveness); (2) a wide scope for improvement, experimentation, and continuously falling prices; (3) facilitating further innovations in products and processes across sectors (Cardona et al., 2013; Krestchmer, 2012; OECD, 2013; ITU, 2012; Czernich et al., 2011; Atkinson and McKay, 2007).

2.2. Conceptualizing and measuring benefits

Overall, our analysis of the literature points to three primary avenues by which ICT can drive economic benefit: the growth impacts of the ICT-producing sector itself, the impact of investment in ICT on the wider economy via capital services and its enhancing effect on multifactor productivity and the surplus benefits to consumers not generally captured in GDP.

2.2.1. Direct growth benefits: The ICT-producing sector

According to Atkinson and Stewart (2013: 3), global output from the ICT-producing sector accounted for 6% of the world's GDP in 2010, more than double the percentage in 1995. Based on data from the OECD, the size of the ICT sector in developed countries, when measured as a share of the total business sector's value added, followed an inverted U-shaped pattern between 1995 and 2011.[7] The average OECD country saw its ICT share increase from 6.6% in 1995 to a high of 9.5% in 2003 before undergoing a slow decline to 5.9% in 2011,[8] in part because of growth of the sector in developing countries.

It is interesting to note that the energy sector, globally, is about 5–6% of GDP and quite stable, about the current size of the ICT sector. As with energy, it appears likely that some countries will experience a rise in the relative size of their ICT sectors and others will have largely offsetting decreases. Therefore, in our economic analysis, we will give limited attention to this aspect of ICT's economic contribution.

2.2.2. Indirect growth benefits: ICT capital services and productivity

Economic production is often explained as a function of capital, labor, and multifactor (or total factor) productivity (MFP or TFP). Each of these factors is a stock that accumulates (or depreciates/declines) over time, which we, and other analysts, use to calculate annual production (a flow) using a Cobb-Douglas or similar production function.

The Conference Board (CB) used a standard growth accounting framework to calculate the contribution of a country's ICT capital services (from IT hardware, software, and telecommunications equipment) to GDP growth over the period from 1990 to 2013 for 122 developing and developed countries (Conference Board undated, 2014a, and 2014b). The CB (see Fig. 1) found that, at the global level, ICT capital contributed between 0.5 and 0.7 percentage points to GDP growth from 1997 to 2013, with developed economies seeing a smaller contribution (0.3–0.6%) than developing countries (0.7–1.9%).

Yousefi's (2011) survey of existing studies on the impact of ICT investment on growth, focusing on the period 1990–2000, also found a positive time trend in ICT's impact. Taken together, the 17 studies surveyed found ICT investment contributed 0.49 percentage points to GDP growth between 1990 and 1995 and 0.72 percentage points between 1995 and 2000.[9]

2.2.3. Consumer surplus

A major part of the Optimist argument concerning ICT's economic impacts is that standard economic measures like GDP do not capture all the welfare or network effects of their use. Consider trying to measure the economic impact of internet-based technologies, where free services like email, search engines, and social networks obviously impact the ways people work and live but do not necessarily result in monetary transactions recorded in national accounts. MGI (2013: 11) estimated that "as much as two-thirds of the value created by new Internet offerings tend to be captured as consumer surplus."

The ICT consumer surplus represents the net monetary value of consumer-derived benefits from consuming an ICT product or service after taking into account: (1) willingness to pay for the service; (2) the actual cost of the services; and (3) any pollution effects arising from the use of the service (i.e. the negative effects of advertising interruptions, loss of privacy, data theft, etc.) (MGI, 2011: 54; OECD, 2013; Dutz et al., 2009; Katz and Koutroumpis, 2013).

[5] Note: each technology's value is given in terms of its total economic value, including contribution to GDP and consumer surplus and the report states that the reported values should not be compared with GDP. It does, however, provide a breakdown for a few of the technologies.

[6] Percentages are calculated by taking MGI's estimated potential economic impact, subtracting their estimated consumer surplus and dividing that by the IFs global GDP forecast for 2025 ($141 trillion).

[7] Total business sector value added refers to the value added by all non-agriculture (incl. hunting and fishing), real estate, and community (non-market activities like public administration, education, and health services) activities (OECD STAN database for Industrial Analysis, available at: www.oecd.org/sti/stan)

[8] Data from the OECD Factbook database. Years with data include: 1995, 2003, 2006, 2008, 2009, 2011. Available at: http://www.oecd-ilibrary.org/economics/data/oecd-factbook-statistics/oecd- factbook_data-00590-en [accessed on 5/11/15]

[9] See the larger background report for this study (Hughes et al., 2015) for a table of country-specific and time-specific values, as well as more general elaboration of information supporting this study.

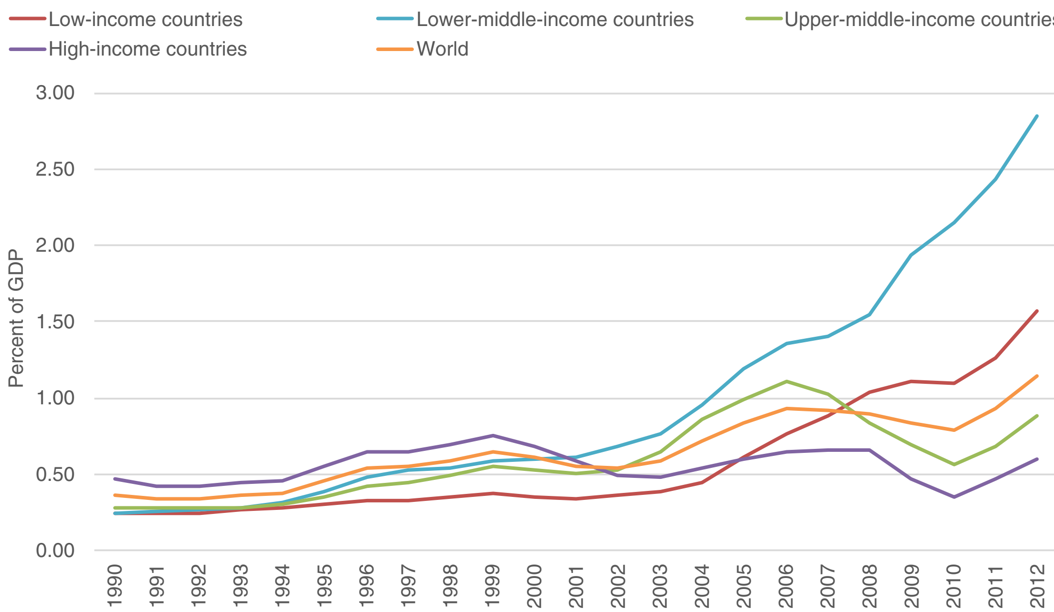

Fig. 1. ICT capital services' contribution to GDP growth by World Bank country income group, 1990–2012. *Note: Simple cross-country averages of raw data used for each income grouping. Source*: Created from Conference Board Total Economy Database, Contribution of ICT Capital Services to GDP Growth, 2014.

Greenstein and McDevitt's (2012, 2011a, 2011b) approach to calculating the annual consumer surplus from broadband is perhaps the most widely cited and adopted method of calculating consumer surplus—the OECD (2013) adopted their approach for its own study of the impact of the internet, the best data source we found on consumer surplus. Greenstein and McDevitt found that consumers in 30 OECD countries enjoyed a surplus of $46 billion in 2010, or about 0.09% of their total GDP in that year (the equivalent of 3% of GDP growth), up from $22 billion (0.05% of GDP growth) in 2006.[10]

The authors also provided a "quality-adjusted" measure of consumer surplus, in order to account for improvements in service quality and network effects from increasing penetration. This approach tends to yield a much higher surplus than the standard approach, $437 billion for the 30 OECD countries in 2010, or about 0.89% of GDP—the equivalent of 28.9% of GDP growth from 2009–2010 Greenstein and McDevitt (2012: 15).

2.3. Conceptualizing and measuring costs

Avoidance of and reaction to adverse cyber events are central to the costs of ICT, but there is no standard typology of such costs. Avoidance primarily involves cyber security spending by individuals/households, organizations (including firms), and governments. We similarly group the costs associated with adverse cyber events across the same three actor and target categories. In addition, we consider the opportunity costs of foregoing use of cyber services or infrastructure due to the threat of attacks or for other reasons.

2.3.1. Cybersecurity and risk mitigation spending

Estimates of cybersecurity spending are scarce, piecemeal, and not confidence-inspiring. But taken together, a decent picture emerges. Based on estimates by the Telecommunications Industry Association (TIA) and Gartner Inc., cybersecurity spending in the United States in 2014 was around $46 billion or 0.3 of GDP, while global spending was around $71 or 0.08% of GDP.[11] While the dollar amounts and percentages may vary by source, all seem to agree that spending on security is set to rise over the coming years as companies become more aware of the cyber threats they face. TIA, for example, forecasts US spending to reach $63.5 billion or 0.35% of GDP within three years, while Gartner Inc. forecasts global spending to grow by 8.2% between 2014 and 2015, to 76.9 billion dollars or 0.1% of GDP with spending on data loss prevention growing the fastest.

This increase in spending is largely due to the fact that costs of preventative spending increase exponentially (diminishing returns) with the pursuit of higher security levels. A survey of 172 technology managers in the US found that companies would need to increase their cybersecurity spending nine-fold in order to stave off 95% of cyberattacks—considered to be the highest attainable level of protection (Engleman and Strohm, 2012). To illustrate the cost to attain a 95% protection level, we can apply Ponemon's multipliers (reported in Engleman and Strohm, 2012) for closing security gaps to TIA's current total US spending figures, producing a cost estimate of around $414 billion or roughly 2.5% of total GDP.

The degree to which national and global cybersecurity spending estimates include government spending as well as that of industry is not always clear—though government spending is almost certainly less than the private sector's. Nonetheless, governments of many developed countries have established significant cyber defense programs and agencies with substantial funding streams. In the US, the Department of Homeland Security (DHS) "spent $459 million on its various cybersecurity programs in 2012. The Pentagon spent roughly eight times as much, not even including the defensive and offensive cyber spending share of NSA's classified budget" (Singer and Friedman, 2014: 200). These figures are in line with market forecasts by Input Inc., which expects federal spending on cybersecurity to grow from $8.6 billion in

[10] These percentages were calculated using the GDP MER historical series in IFs version 7.15.

[11] "Gartner Says Worldwide Information Security Spending Will Growth Almost 8 Percent in 2014 as Organizations Become More Threat-Aware," *Gartner.com*, August 22, 2014. Available at: http://www.gartner.com/newsroom/id/2828722 [accessed on 5/6/15] and "TIA's 2014–2017 Market Review & Forecast," *Tiaonline.org*, 2014. Available at: http://tiaonline.org/resources/market-forecast [accessed on 5/6/15].

2012 to $13.3 billion in 2015 (or approximately 0.08% of US GDP).[12] Strategic Defense Intelligence (SDI) forecasts the global military IT, data, and computing market will reach $68.6 billion by 2022 (nearly 0.07% of GDP in our calculation).[13]

2.3.2. Adverse cyber event costs

Coupled with ever-increasing reliance on ICT comes the potential for hacktivists, firms, criminals, terrorists, and governments to disrupt networks, steal data and identities, cause physical damage and loss of life, and in general exploit vulnerabilities in ICT to their own ends. The literature is rife with speculation about the potential for sensational cyber-attacks or cyber wars to disrupt entire industries or crash national networks.

The cyber threat landscape is characterized by two key dimensions: actors/targets and motivations/actions (Rid, 2013; Cavelty, 2012; and Lachow, 2009). There is no single agreed upon actor/threat taxonomy within the field of cybersecurity. We have adopted the widely cited classification of former Special Advisor on Cybersecurity to the White House, Richard Clarke: (1) hacktivists—individuals or groups whose motivation for carrying out cyber-attacks is ideological; (2) cyber criminals—individuals or groups that launch attacks aimed at financial gain; (3) cyber-espionage—attacks with the primary motive of acquiring intellectual property from firms or governments; and (4) cyberwar—destructive attacks launched from politically or militarily motived state or non-state actors (Clarke and Knake 2010; Clarke 2009). In our forecasting efforts, we focus not on individual events but on the country-year pattern of events.

We want to be able to associate likelihood and economic costs with each type of actor/threat and each target (individuals, organizations, and governments). Specifying the appropriate probabilities and costs requires estimates of annual country-wide costs that are difficult to find and vary so significantly that any figure must be taken with great caution. For example, estimates of the cost of cyber-espionage to the US range from $2 billion to $500 billion, with the Center for Strategic and International Studies (CSIS) suggesting that the US cost of espionage and cybercrime combined is around $113 billion (CSIS, 2014; see also CSIS, 2013).

CSIS (with McAfee) published estimates of the combined cost of cybercrime and cyber-espionage as a percent of GDP for 28 countries which suggest that Germany, the Netherlands, the US, China, and Singapore are the five countries most negatively impacted by such attacks (see Fig. 2). The study found that G20 countries bear the predominant burden of costs associated with cybercrime and cyber-espionage, with damages of over $200 billion in the four largest economies alone. Lower-income countries, while less of a target now, are expected to face growing threats as their ICT usage increases.

What are the probabilities of adverse cyber events? IBM and Ponemon provide estimates derived from surveys regarding the likelihood that a company will experience a data breach in a given period of time. IBM (2013: 5) reported an estimated 69% likelihood that a company will experience one or more minor disruptions over a 24-month period, with a 23% change of a substantial disruption. Similarly, Ponemon (2014: 18) estimated that over a 24-month period there is a 22% likelihood that a company will experience a data breach involving at least 10,000 stolen records and a 1% chance of a breach with 100,000 or more records. In terms of cyber-espionage attacks, Verizon (2014: 39) estimated that the US is targeted in over half of the attacks worldwide. Furthermore, it indicated that cyber-espionage has been increasing in relative prevalence since 2009 (Verizon, 2014: 9).

The studies suggest that no country is immune and that the probability of experiencing a malicious cyber event in a given year, particularly those categorized as criminal or espionage, is not statistically different from one. The contested possibility of cyberwarfare is one exception to this observation. We therefore assign a probability of 1 for all cells in the activity-probability-cost schema except those in the cyber conflict/war row where they will be very nearly 0 for most country-years. The other cell for which the probability will be very near 0 is that of criminal attacks on governments. Thus the central variable in exploring the risk associated with an adverse cyber event becomes the total country-year costs of each event cell.

The values used in our cyber risk matrix are (to the best of our ability) calibrated to estimates found in the literature discussed above. A primary calibration point comes from CSIS (2014), which indicates the overall cost of cybercrime and cyber-espionage in the US to be 0.64% of GDP. But when estimates could not be found, or when there were conflicting values, estimation was still necessary. For example, with no estimates for the cost of US involvement in a cyberwar, we have assumed 1.0% of GDP (roughly twice the 2014 cost of the wars in Iraq and Afghanistan). Because of the great leaps made in such estimation, the scenario analysis undertaken with IFs becomes especially important.

The product of our probabilities and costs gives us the overall cost of adverse cyber events as a percent of GDP. Our first rough-cut estimates indicate that organizations (primarily firms) bear the lion's share of risk associated with malicious cyber-attacks, followed by individuals, and then governments. Were there, of course, any intergovernmental cyber conflict, that ordering could quickly change. Our calculations suggest that, for a country like the United States, total annual costs from adverse cyber events are about 0.63% of GDP.

2.3.3. Opportunity costs

Opportunity costs are costs borne by countries, organizations, and households alike in the form of risk-adverse behavior that limits the benefits they might have otherwise received. Opportunity costs generally originate from one of two sources: (1) a conscious decision not to use ICT services and infrastructure (so as to avoid risks or to control populations), and (2) the underdevelopment of ICT infrastructure for other reasons including cultural orientation or weak actor capacity. We make no effort to model different sources of opportunity costs but rather to estimate total magnitude of them.

To illustrate ICT opportunity costs, Fig. 3 shows the strong relationship between ICT development and GDP per capita. Relative to countries like South Korea that have higher levels of ICT development than expected given their level of per capita income (and therefore no opportunity costs), countries like Cuba likely face large opportunity costs by not investing in ICT and the economic benefits they could provide. In Cuba's case, their level of ICT development is only about 1/2 of what we would expect given its GDP per capita. This shortfall could easily be costing the country something close to 1% of growth in its GDP.

2.4. Comparing the Benefits and Costs of ICT/Cyber

Comparison of the aggregate benefits with the aggregate costs across the three elements in each typology should provide us with annualized snapshots of the state of cyber risk economics. However, such snapshots do not tell the whole benefits versus costs story. It is important to also consider the cumulative costs and benefits that accrue to a country over time.

The distinction between annual and cumulative costs and benefits is important because the economic benefits are heavily manifested from ICT's rising share of productive capital stocks and consumer benefits, meaning that they accumulate and compound over time. Barring a large-scale, sustained threat, the costs directly or indirectly associated with adverse events do not tend to decrease this stock. Therefore, even in a hypothetical future in which the annualized costs eventually

[12] Gerry Smith, "Former Government Officials Stand to Profit from Cybersecurity Boom," *Huffingtonpost.com*, September 14th 2011. Available at: http://www.huffingtonpost.com/2011/09/15/former-government-officials-cybersecurity-.

[13] "The Global Military IT, Data and Computing Market 2012—2022," *ASDReports.com* November 8th 2012. Available at: https://www.asdreports.com/news-903/global-military-it-data-computing- market-20122022 [accessed on 5/6/15].

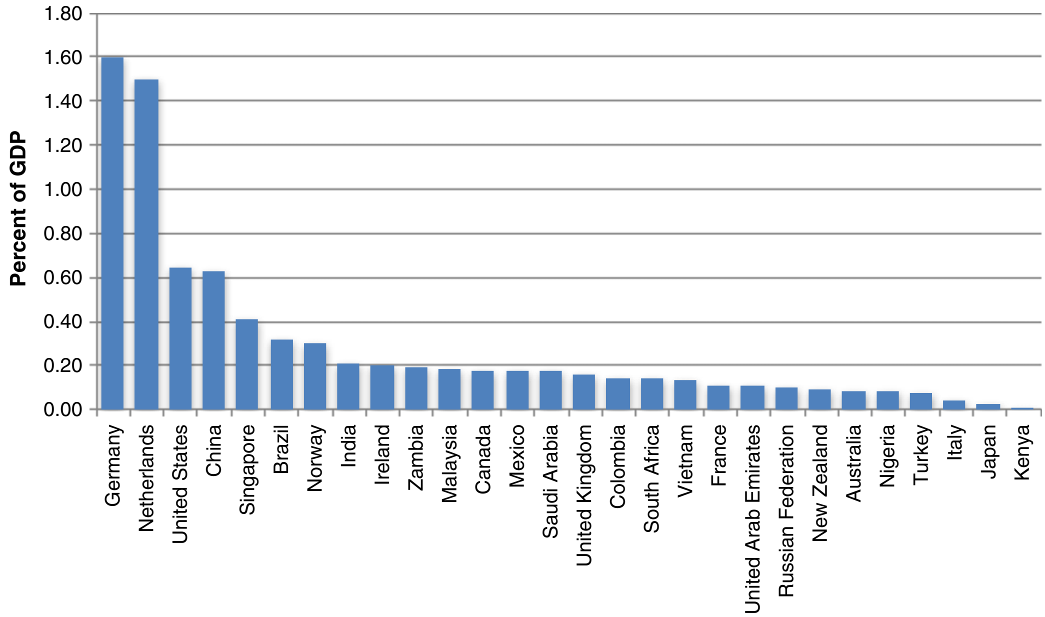

Fig. 2. The cost of cybercrime and cyber-espionage expressed as a percent of GDP.
Source: Figure created from data in CSIS (2014: 21).

overpower the incremental annual benefits at some point in the future, the cumulative benefits accrued over the same period may still heavily outweigh the cumulative costs. This insight weighs against the notion of an imminent "cybergeddon" — a future world where the costs of ICT are so high that the technologies become almost unusable.

3. Calculations: Representing ICT/cyber in the International Futures system

Although the literature and available data do not provide an integrated foundation for forecasting ICT benefits and costs, our compilation of sources has provided enough information to develop basic formulations and then to create a set of scenarios around key elements of uncertainty.

3.1. The IFs system as model foundation

The International Futures (IFs) forecasting system is housed at the Frederick S. Pardee Center for International Futures at the University of Denver's Josef Korbel School of International Studies but is freely available for use and further development by others (www.pardee.du.edu). IFs includes detailed models of demographic, economic, sociopolitical, education, health, infrastructure, energy production, agricultural, and governance subsystems for 186 countries interacting in the global

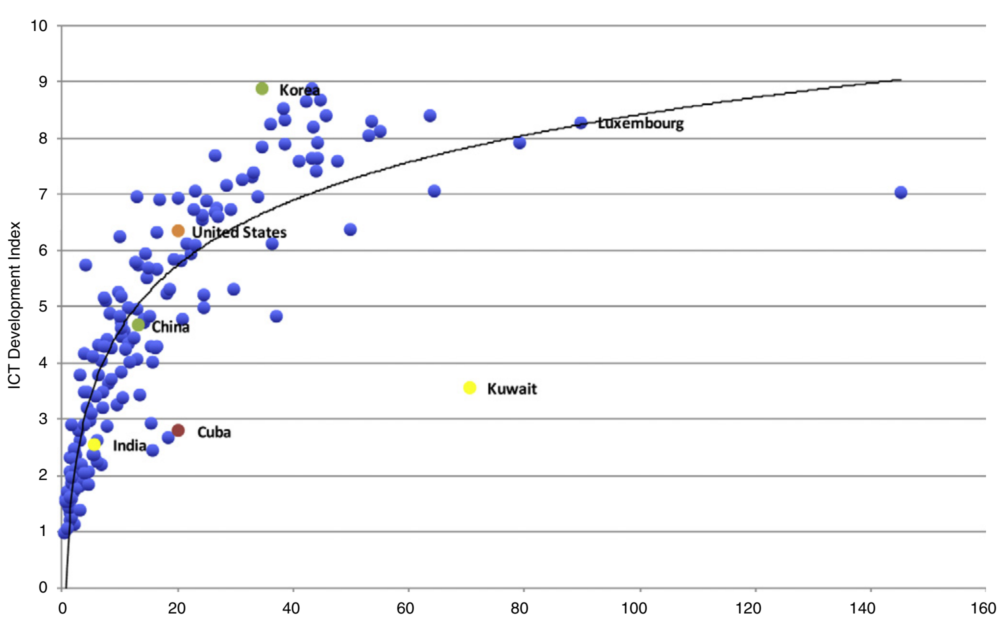

Fig. 3. Relationship between GDP per capita at PPP and ICT Development Index.
Source: Using data from the ITU and World Bank's World Development Indicators.

system (Hughes and Hillebrand, 2006; Hughes, 2016). Extensive linkages connect separate models of the IFs system, providing the ability to analyze the issue area interactions identified in this paper. Most of these models are comparable to standalone models in the issue areas represented, though some like that for health, are unique to the IFs system. The models within IFs of special interest for this paper include the demographic, economic and infrastructure systems.[14]

IFs represents population using a standard cohort-component structure initialized with the most recent data revision from the United Nations Population Division. Fertility rates and mortality patterns endogenously respond to other model variables including income and educational levels. Migration rates come from exogenous forecasts provided by the International Institute for Applied Systems Analysis (Samir and Lutz, in press).[15]

The economic model, which draws most heavily on data from the Global Trade and Analysis Project and the World Development Indicators, represents the economy in six sectors: agriculture, materials, energy, manufacturing, services, and information and communications technologies. It is a general equilibrium-seeking model using inventories to provide price signals that chase equilibrium over time. A Cobb-Douglas production function (following insights of Solow [1956 and 1957] and Romer [1990]) endogenously represents contributions to growth in multifactor productivity from human capital (education and health), social capital and governance (domestic security, low corruption, democracy), physical and natural capital (infrastructure and energy prices), and knowledge development and diffusion (research and development and economic integration with the outside world). A Linear Expenditure System represents changing household consumption patterns. A social accounting matrix assures balances in intersectoral and all other flows.

The infrastructure model represents many ICT variables such as mobile phone and PC ownership rates and both fixed and mobile broadband prevalence. Additionally, it includes variables for road transportation, water and sanitation, and electricity. See Rothman et al. (2014) for detailed treatment.

3.2. Forecasting ICT/Cyber benefits and costs

Fig. 4 provides a high level schematic diagram of the risks or costs and benefits of ICT as structured in IFs. There are two main determinants of the various benefits and costs. The first driver is the pervasiveness of ICT within countries in any year at any point in time. The second is the extent of cybersecurity and the probabilities and costs of adverse cyber events. Both of these determinants are, in turn, affected by certain assumptions represented by the first box in Fig. 4 (upper left), which represents the exogenous rate of technological change and social and political decisions that might affect ICT diffusion and security (such as greater or lesser restrictions on ICT deployment and use). This section first discusses the representation of ICT/cyber pervasiveness and the nexus of variables around cybersecurity spending and adverse event probability and cost, and then moves to discussion of other ICT/cyber benefit and cost variables.[16]

3.2.1. ICT/cyber pervasiveness

The International Telecommunication Union (ITU) collects and provides a large number of data series. Among these, the ITU built the ICT Development Index (IDI) to track ICT development across 166 countries as a composite of three sub-indices: (1) *Access* to ICT infrastructure and services; (2) *Use* of ICT; and (3) *Skills* for ICT uptake. We have created a close variant of the IDI in IFs (ICTINDEX) because the model already contains and forecasts most of the variables used in construction of the sub-indices.[17]

One weakness of the IDI is that it is closely tied to current ICT/cyber technology, particularly mobile phones and broadband use, which are likely to saturate over time while other ICT/cyber technologies continue to advance. Thus, the IDI may underestimate future prevalence. We added a multiplier to our version of the IDI for use in scenario analysis to postpone this saturation.

3.2.2. Cybersecurity spending and security levels

Cybersecurity spending as a percentage of GDP (ICTCYBSPEND) serves two purposes. First, it is one of the key costs of cyber risk. Second, it should, *ceteris paribus*, increase cybersecurity. The relatively scarce data suggest that spending has been rising over time, both absolutely and as a percentage of GDP. We have put into IFs a formulation, which, supported by the literature, drives spending as a portion of GDP by (1) GDP per capita level and (2) the ICT pervasiveness index. We also added a multiplier allowing strong scenario control over it, to reflect social choices and policies. We formulated our cybersecurity spending to saturate over time at around 0.4% of GDP.

We further created a cybersecurity index (ICTCYBSECUR) based on the ITU's Global Cybersecurity Index (GCI). The GCI ranks the cyber security capabilities of 195 countries across five categories: (1) legal measures; (2) technical measures; (3) organizational measures; (4) capacity building for awareness and access to resources; and (5) the level of intrastate and international cooperation. Unlike our representation of the IDI, we cannot forecast the cybersecurity index from other variables in IFs. We instead forecast it from driving variables, namely the ICT development Index and cybersecurity spending. The formulation is tied most fundamentally to the magnitude of the ICT development index as indicated in Fig. 5. It may surprise some that cybersecurity rises with ICT/cyber pervasiveness rather than falling, but this is entirely consistent with the findings of a Microsoft study (Burt et al., 2014) that showed malware control costs rising with development generally.

3.2.3. Adverse event probabilities and costs

The second cost associated with cyber risk is that of adverse events (ICTCYBEVCOST), also represented in IFs as a percentage of GDP. IFs computes the basic core of adverse event cost as a function of two elements specified via user-modifiable parameters: (1) the probability of adverse events by actor category (hacktivism, cybercrime, cyber-espionage, and cyber-terrorism) and target (households, firms/organizations, and governments); and (2) the cost of such adverse events. Around that parametric core, total cyber costs increase with ICT/cyber pervasiveness and decrease with cybersecurity. Again, the user can change the trajectory of event costs through scenario creation. Because the data are relatively strong, we began with the values and probabilities pieced together for the United States and scaled other country-years relative to those.

3.2.4. ICT/cyber contributions to economic growth (productivity) and possible opportunity costs

The third cost associated with ICT, namely opportunity costs (ICTCYBOPCOST) is only meaningfully conceptualized in relationship to the productivity benefit available from ICT (ICTCYBBENFIT) and the portion of that forgone by not fully embracing ICT. Earlier discussion showed how difficult and uncertain analyzing ICT's impact on productivity and GDP growth can be. The numbers produced by that analysis would, however, be consistent with a crude estimate that approximately ¼ of productivity gains could, on average across countries, come from ICT. We would expect somewhat more absolute growth contribution in countries with faster MFP growth (e.g. the 5% of China or 4% of India) than those with slower growth (e.g. the roughly 1.2% of the US),

[14] Documentation on each model is available at http://www.pardee.du.edu/node/484.
[15] Detailed migration data provided by personal communication from Samir KC.
[16] Hughes et al. (2015) provide more detailed explanation with full model and equation documentation.
[17] Such indices are, of course, widespread in literatures across all important issue areas of IFs, from agriculture (Valipour, 2015) to technological change.

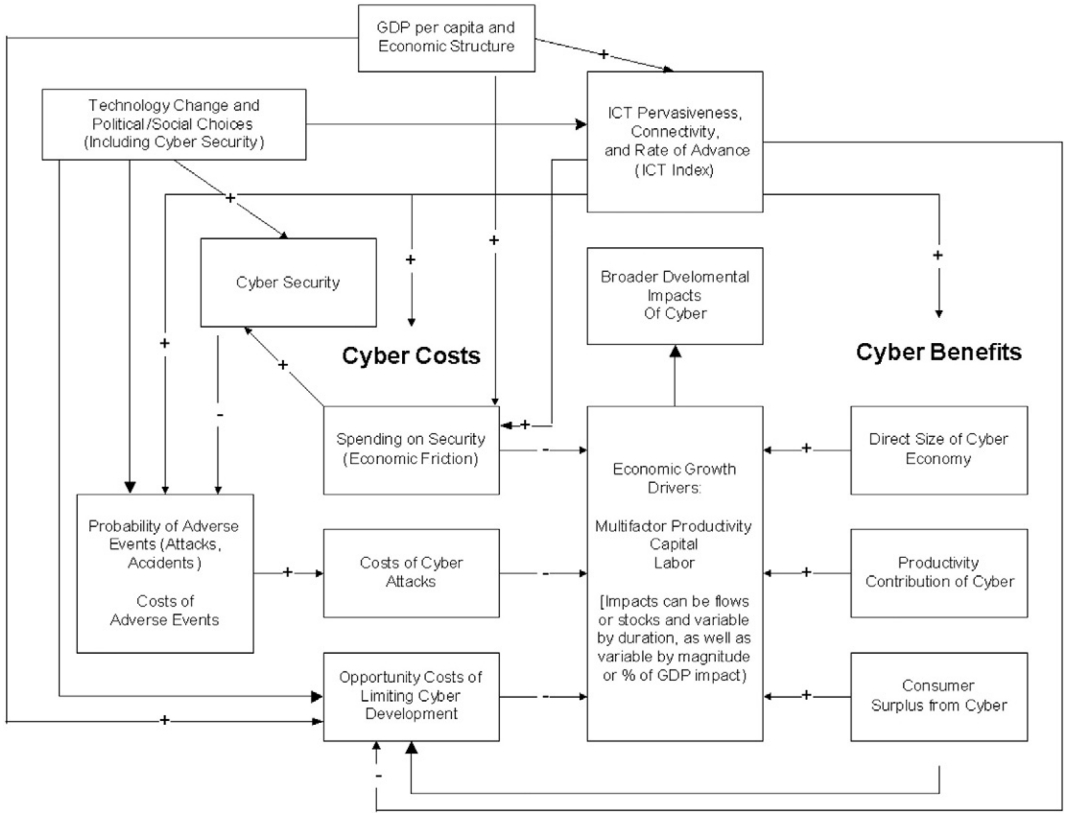

Fig. 4. High-level overview of the forecasting in IFs of cyber risks/costs and benefits.
Source: Authors' conception.

allowing us to retain the fixed share assumption and conclude that ICT might be contributing roughly 1.2% to growth in China and roughly 0.3% in the US. This approach is consistent with the observation that ICT has greater potential contribution to growth in developing than developed countries. Rather than a fixed 1/4 assumption, however, the actual parametric specification of the ICT fractional contribution to MFP is determined by a function developed by trial and error so as to ensure that the ICT/cyber growth benefits fit historical data from the Conference Board as well as possible across global income-category groupings. That function decreases the basic fractional share from 30%

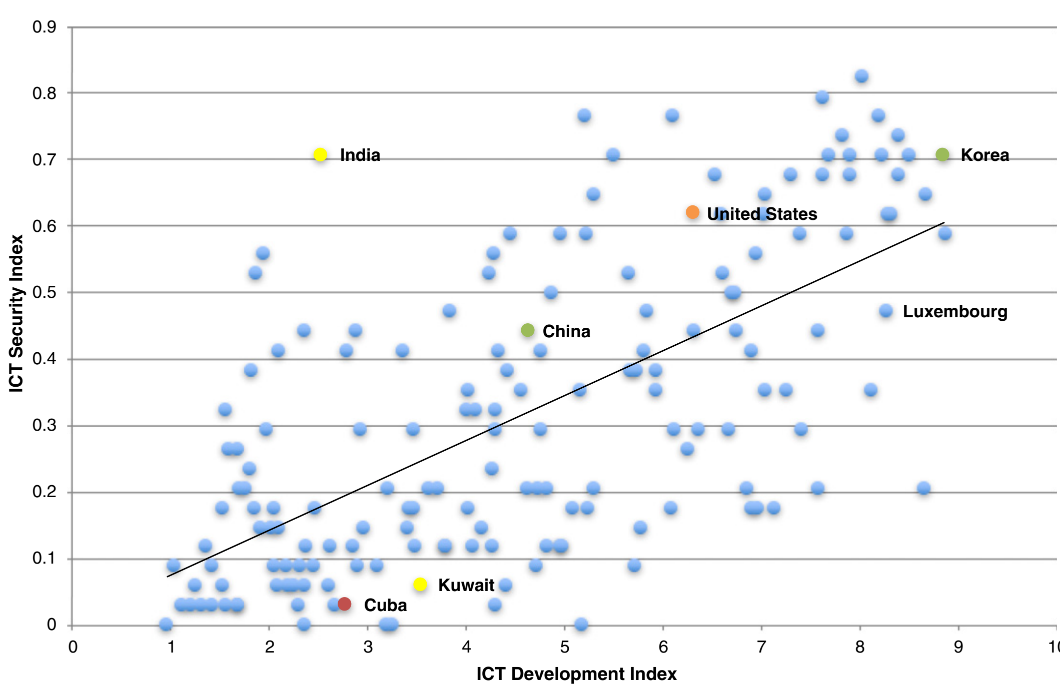

Fig. 5. Cybersecurity index as a function of the ICT Development Index.
Source: Using data from the ITU.

to 15% with increasing GDP per capita. Around this basic calculation, the actual growth contribution is further influenced by the ICTINDEX, reflecting the pervasiveness of ICT relative to the level expected given GDP per capita.

Turning to opportunity costs, Fig. 3 earlier provided information about the level of expected ICT pervasiveness as a function of GDP per capita at purchasing power parity. The model calculates opportunity costs only for countries below the line where the magnitude of those costs is the product of the potential productivity benefit times the proportional distance below expected ICT pervasiveness levels.

3.2.5. Consumer surplus

Beyond ICT's contribution to productivity and GDP growth, its second primary economic benefit is to consumers and is appropriately called consumer surplus. The Organization for Economic Co-operation and Development (OECD, 2013) provided good estimates. The average annual contribution is approximately 0.2% of GDP, making it somewhat smaller than the contribution of ICT/cyber to MFP advance. Larger economies (notably the United States, Japan, Germany, and the United Kingdom) tend to have lower annual consumer surpluses, not exceeding 0.1% of GDP per capita, probably reflecting their early ICT adoption.

We created a forecasting formulation quite similar to that for the economic growth benefit, using an estimate of consumer surplus contribution as a share of moving average GDP growth based on a function that results in initial forecasting values comparable to historical data for OECD countries. That value is then scaled up or down for countries with more or less ICT pervasiveness.

3.3. ICT/Cyber total and cumulative benefits and costs and forward linkages

Forecasting the net costs or benefits as percentages of GDP allows us to compute cost and benefit summary variables on a country-year basis. For accumulation of those over time we use a simple sum of the costs and a compounding of the benefits.

Although it would be desirable to account for the specific source of cost streams (some portion of that could crowd out investment, also with a compounding effect over time) we do not do so, a known but relatively minor analytical weakness. Similarly, it would be desirable to link the benefit stream of ICT forward to economic growth, and failure to do so is another known weakness. We do, however, link forward the ICT index to the calculation of MFP and, because that is a direct driver of benefits, it greatly ameliorates that omission.

4. Results: Scenarios and forecasts of ICT benefits and costs through 2030

All scenarios build on the IFs Base Case scenario. The Base Case is not a simple extrapolation of variables in multiple issue areas, but rather the dynamic, nonlinear output of the fully integrated IFs system. For example, IFs forecasts of key drivers, such as GDP per capita and population are foundational underpinnings of our Base Case ICT forecasts. Further, changes in assumptions in ICT pervasiveness, benefits, and or risks (costs) result in changes in demographics, economics, and all other systems in IFs. Feedback loops across the many components of the IFs system mean that interventions may accelerate (or dampen) the benefits and costs of ICT and other modeled aspects of human development.

4.1. Defining a scenario space

Earlier discussion drew out two primary dimensions of uncertainty that frame the level of and balance between the benefits and costs associated with ICT. The first involves the unfolding of the technologies themselves, specifically the rates of potential continued development and pervasiveness. This unfolding has particular implications for benefits, because development and deployment of ICT contributes to economic productivity and consumer surplus. The second key dimension of uncertainty involves the future probability and costs of adverse cyber events. Fig. 6 illustrates the manner in which these two dimensions of uncertainty frame a scenario space and Box 1 lists model interventions.

In the upper-left-hand quadrant, *The Wave Plays Out*, the benefits from the current wave of ICT largely saturate with mobile broadband access—which some analysts have argued is likely to be the last major ICT development in terms of its economic impact—allowing significant stabilization of the cyber world and allowing defensive capabilities to catch up with and overcome offensive capabilities. Yet mobile broadband appears much more likely to represent just the latest sub-wave of ICT with many more waves to come. Hence, we include this scenario more out of a sense of completeness rather than a belief that it represents a likely outcome.

In *Electricity-like GPT*, the growing criticality of ICT across the global economy and societies around the world drives continued and rapid economic growth and underpins new waves of technologies. This centrality incentivizes governments and many social actors (including corporations) to work together to increase defensive capabilities with redundancies and recovery mechanisms, thereby keeping the costs of offensive cyber actions under control.

In *Insecurity Undercuts Benefits*, offensive capabilities gain the upper hand; increasingly sophisticated attacks from hacktivists, criminals, terrorists, and governments inflict severe costs causing many actors to either spend more on cybersecurity or curtail their use of the technologies, reducing benefits and slowing the pace of further technological development.

In *Constant Battle for Security*, ICT again increases in criticality, but governments and other actors—who worked together successfully in *Electricity-Like GPT*—are unable to coordinate their actions or even work at cross-purposes, while independent actors aggressively push new technologies forward, each providing new benefits but also new vulnerabilities to adverse cyber events. The result is a back and forth between offensive and defensive capabilities.

4.2. Base case global summary of benefits and costs

Before looking at variation of ICT benefits and costs across scenarios and across global income-level groupings, it is useful to see the Base Case forecasts for the world (Fig. 7). It provides several important foundational insights. First, the annual contributions of ICT to GDP growth and adverse events are roughly similar in magnitude globally, as are security spending and consumer surplus, with opportunity costs calculated to be small. Second, growth contributions and adverse event costs each have slightly more than twice the magnitude of consumer surplus and security spending. Third, there is an upward trend in both costs and benefits.

We shall, of course, see that cumulative benefits and costs have quite different patterns, but we can show those in the context of the scenarios.

4.3. Comparing costs and benefits across scenarios and income categories

The picture of annual net benefits varies greatly across country income levels and scenarios. Fig. 8 suggests several insights concerning the pattern of net annual benefits across the four scenarios (ordered in quadrants like those that defined the scenarios in Fig. 6). First, already in 2010, the annual costs outweigh the benefits for high-income countries, due mainly to saturation effects, and that gap grows over time in all scenarios. Second, in sharp contrast, all other income groups saw positive net benefits ranging from 0.5 to just above 2% of GDP in 2010, with net benefits remain positive through 2030 in all scenarios except *Insecurity Undercuts Benefits* (where all income groups see the net benefits of ICT turn negative from −0.5 to −1.5% of GDP). But while annual net benefits remain positive for developing countries in the other scenarios, in *The Wave Plays Out* and *Constant Battle for Security*, they

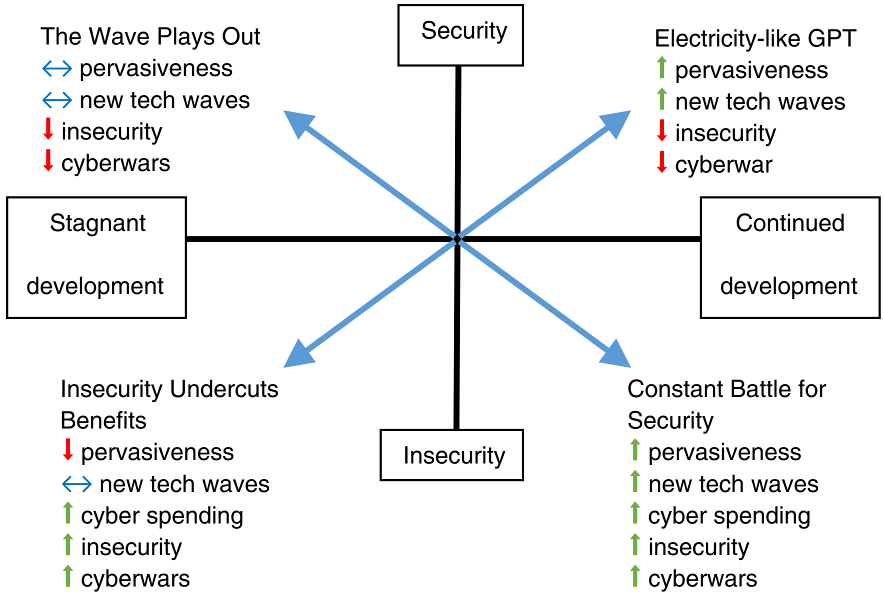

Fig. 6. Dimensions of uncertainty and associated scenarios.
Source: The authors.

actually decline over time due to saturation effects and the stalling of technology advance (*Wave*) and the increasing cost of adverse cyber events *(Battle)*. It is only in *Electricity-like GPT that* the net benefits grow for all developing country income categories through *2030*, thanks to new technology waves undoing the saturation effect. Third, the net benefits of low-income countries remain larger than those of both lower- and upper-middle income countries throughout the time horizon and across scenarios as they have the most room for network growth and therefore are likely to suffer the least, economically, from adverse events. Fourth, outside of *Electricity*, developing countries show noticeable convergence with high-income countries over time—with upper-middle-income countries unsurprisingly exhibiting the greatest movement toward the pattern of high-income countries.

Box 1
Specifying the interventions (all have an initial year of 2016).

Pessimistic on technological advance
The Wave Plays Out—assumes saturation of ICT Development Index, with no new waves of technology; the costs of hacktivism, cybercrime and cyber-espionage drop 20% by 2030, reflecting dominance of defensive capabilities in a technologically stagnating cyber world; cyberwar and cyber-terrorism costs/probability remain zero throughout the time horizon.
Insecurity Undercuts Benefits— assumes saturation of ICT Development Index, no new waves of technology; the costs of hacktivism, cybercrime, and cyber-espionage increase by 30% by 2030 as offensive capabilities win out—even with a 20% increase in cybersecurity spending by 2030; and the probability of cyberwar increases to 50% by 2030.
Optimistic on technological advance
Electricity-like GPT—new waves of ICT technologies lead the ICT Development Index to double by 2030; the costs of hacktivism, cybercrime and cyber-espionage are reduced by 20% by 2030, reflecting cooperation by primary actors; cyberwar and cyber-terrorism costs/probability remain zero throughout.
Constant Battle for Security— new waves of ICT technologies lead the ICT Development Index to double by 2030; the costs of hacktivism, cybercrime, and cyber-espionage increase by 30% as new disruptive technologies give offensive capabilities the edge—even with a 20% increase in cybersecurity spending by 2030; and the probability of cyberwar increases to 50% by 2030.

Turning to the analysis of net cumulative benefits or costs over time (Fig. 9), even with the exceptionally high costs of *Insecurity Undercuts Benefits*, the compounding cumulative contributions of ICT to productivity growth and consumer surpluses create positive cumulative net returns—if that were not true we would likely see a world in which nearly all cyber activities were shut down by actors seeking to minimize long-term losses. Note that the total global cumulative benefit of *Electricity-Like GPT* is roughly $35 trillion more than the total net benefits of *Insecurity Undercuts Benefits*. The broader impact of this is that annual global GDP at PPP in 2030 is approximately $8 trillion higher in *Electricity-Like GPT*. To put this in context, the world GDP in 2030 is $138 trillion and cumulative GDP from 2010 through 2030 is $2,060 trillion.

Again, of course, there is great variation across global income levels and regions, as well as across scenarios. Fig. 10 shows the cumulative net benefits across global income groups by scenario. While in *Electricity-Like GPT* upper-middle-income countries gain $68 trillion dollars in cumulative benefit, higher-income countries gain significantly less, at $42 trillion. Lower-middle-income countries have $25 trillion net benefits and low-income countries, in spite of their very much greater benefits as a portion of GDP, see only $3 trillion.

Overall, our scenario analysis shows the great uncertainty of global futures with respect to the benefits and costs of the unfolding cyber world. The interaction of the huge uncertainties around the technologies themselves with the also very great ones surrounding the behavior of government and non-governmental actors creates extremely different global and regional futures. If the great wave of ICT advance continues to unfurl in coming decades, the stakes around shaping better rather than less good or even bad worlds are very high. There are, of course, some commonalities across the scenarios—even if the challenges of offensive actors to defensive ones grow, and the longer-term economic benefits of ICT for economies and consumer surpluses saturate, the net cumulative benefits of ICT to humanity will still be measured in the tens if not hundreds of trillions of dollars. Thus, even the negative scenarios are remarkably positive.

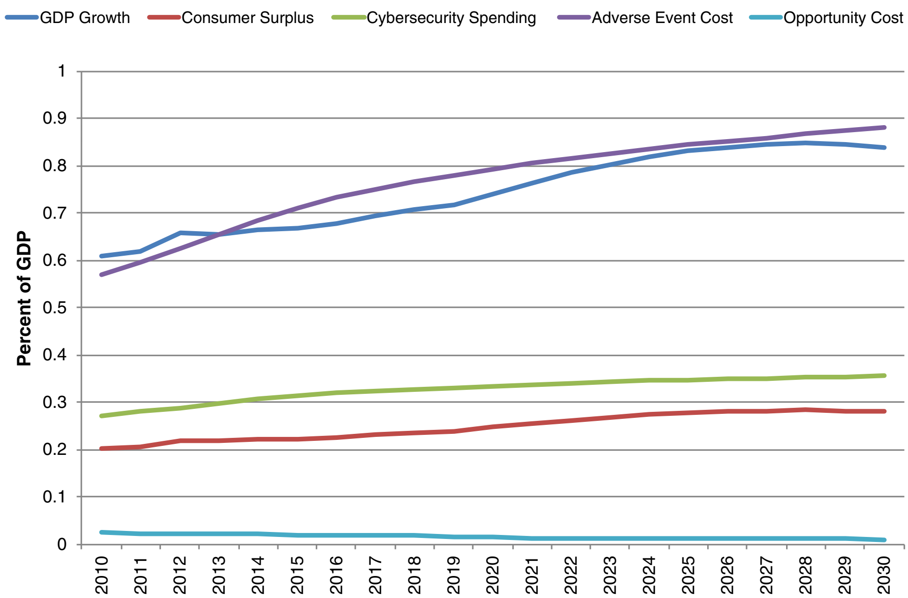

Fig. 7. ICT/cyber annual global benefits and costs, base case, 2010–2030.
Source: IFs version 7.17.

5. Conclusions

This paper has surveyed much of the existing literature and data on the benefits and costs of ICT and their variation across time and countries. We found that, in general, the greatest benefits of ICT come from its compounding contributions to growth and productivity across all sectors of the economy, much like earlier general-purpose technologies like steam and electricity, while the greatest costs are those associated with successful adverse cyber events.

On a global basis, the annual balance of benefits and costs has been changing and it appears quite likely that annual costs will come to outweigh (new or incremental) annual benefits in the near term, as they already appear to do in high-income countries. Yet, even in this annual analysis, net benefits are likely to persist through 2030 for all developing country income groupings.

But the nature of ICT's contribution to capital stocks and multifactor productivity means that the benefits of ICT carry over and compound across time; hence, the cumulative compounded sum of economic benefits is almost certainly to be much larger today, even, than the cumulative but additive sum of costs—a situation all but certain to continue.

The value of this paper and the larger project of which it was part (see Hughes et al., 2015; Healey and Hughes, 2015), has been to identify these conceptual elements, to initialize their value with the best data we

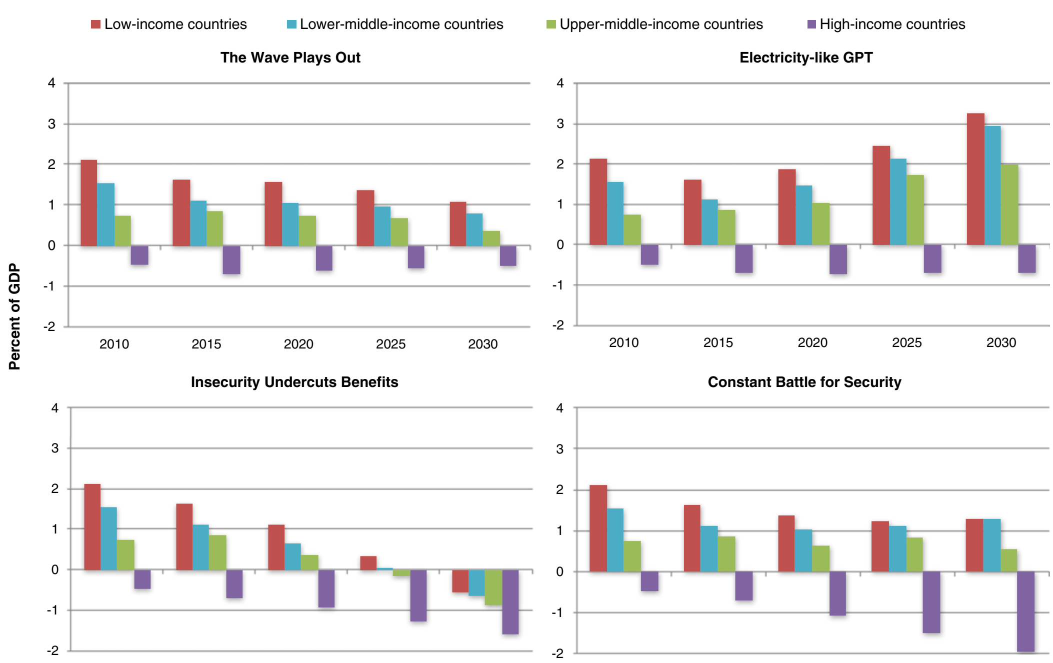

Fig. 8. Annual net ICT/cyber benefits or costs as a percentage of GDP, by income group, by scenario, 2010–2030.
Source: IFs v7.17.

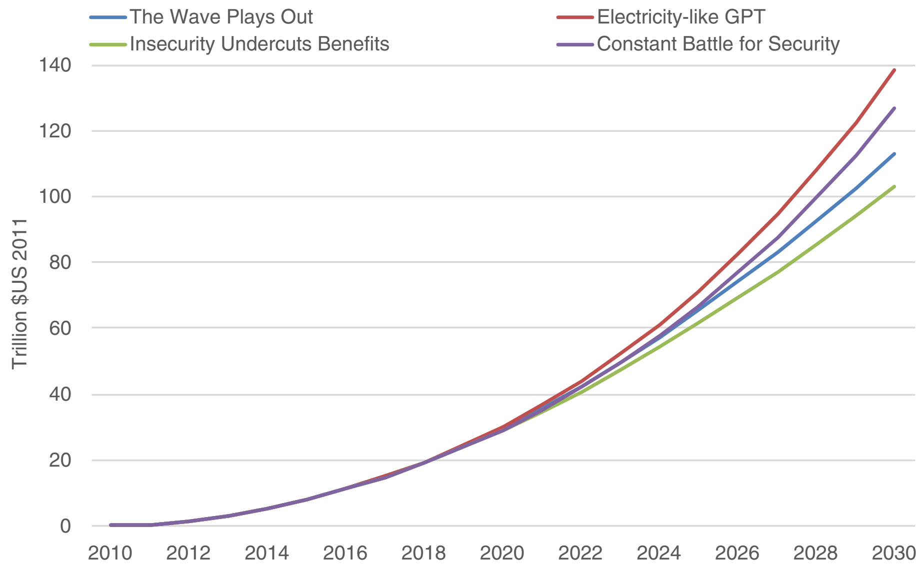

Fig. 9. Global cumulative net ICT/cyber benefits in trillion $US 2011 dollars, by scenario, 2010–2030.
Source: IFs v7.17.

could find, to build forecast formulations that seem consistent with theoretical understandings and past development, and to enhance our ability to explore alternative assumptions motivated by potentially very different scenario stories.

We recognize the inevitable limitations associated with each of these contributions and that uncertainty exists along several aspects of this paper, including: (1) the future pattern of technology advance, including the possibility for technological discontinuities instead of the successive wave model adopted here; (2) the exact level of ICT's contribution to productivity and GDP growth; (3) the probability and impact of severe adverse cyber events like cyberwar.

This paper and the IFs model enhancements provide an initial foundation for exploring each of these uncertainties. Additional model refinement (like the linking of consumer surplus back to economic growth) may reduce some uncertainty, but further reduction will also depend on the availability of more extensive and detailed data sets. It will also depend on continued improvements in mapping of the pattern of technology advance over time and specification of the relationship between ICT and various costs and benefits, especially economic growth, consumer surplus, and adverse event costs. In all, our hope is that the platform created here can continue to be used and refined so as to better understand the balance and risk and reward in the cyber world.

Fig. 10. Cumulative net ICT/cyber benefits or costs in trillion $US 2011 dollars, by income grouping, by scenario, 2010–2030.
Source: IFs v7.17.

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