Online Annex 2.1. Financing Constraints and the Strategy for Investment[1]

This annex presents a model of endogenous debt and sovereign default risk, for economies borrowing externally in foreign currencies, to answer the question of whether such countries should borrow to invest, and how aggressive should the strategy be, depending on some key macroeconomic characteristics. The results of the model highlight the importance of the response of risk premia for the success of a public investment stimulus.

A. The Model

The model is developed in the tradition of the recent quantitative sovereign debt literature (Mendoza and Yue 2012; Asonuma and Joo 2019). Sovereign bonds are one-period noncontingent assets, and the government uses them to smooth private consumption and allow for the financing of public expenditure. Sovereign yields depend on the likelihood that the economy will default on its debt. If the country defaults, it loses access to credit markets for some periods. Losing market access is costly, as it reduces the economy's opportunities to borrow to mitigate the impact of further macroeconomic shocks and it imposes production costs (proxying sanctions by other countries or distortions to supply chains due to the loss of access to trade credit). Such punishment for defaulting determines the degree of debt repayment enforcement, since the government compares the benefits of defaulting (not having to service its debt) to its costs when deciding whether to default.

Households maximize their lifetime welfare, which depends on private consumption, leisure, and government consumption (social expenditure), which is required to at least cover "basic social needs." Firms in the economy produce goods using labor, fixed private capital, and intermediate exportable and importable goods. A share of the importable intermediate goods must be financed in advance. Firms' financing costs in international markets are assumed to move one-for-one with the government's financing costs.[2] The economy is hit by stochastic shocks: total factor productivity (TFP) is a function of an exogenous aggregate shock that follows an AR (1) process with autocorrelation ρ and variance σ^2. The model also introduces an active role for fiscal policy, through the inclusion of different tax instruments —consumption, labor, and profit taxes —and expenditures —public consumption and investment.

To investigate the impact that different public investment strategies could have on the equilibrium of the economy, public investment is considered exogenous if the economy has access to international markets. But during periods of sovereign crises, public investment is chosen optimally, which allows an analysis of the tradeoff faced by governments when fiscal constraints are acute.

B. Public Investment Multipliers and Fiscal Risk

Public investment builds up the stock of public capital and raises TFP, the productivity of inputs, and thus profits, wages, consumption and welfare. Higher income and consumption levels for the households translate into higher tax revenues for the government, increasing its fiscal space.[3] However, when fiscal

[1] This online annex was prepared by Sandra Lizarazo of the Fiscal Affairs Department.

[2] Strong evidence connects sovereign default and private credit conditions for both emerging and advanced economies. Arellano and Kocherlakota (2007) and Mendoza and Yue (2012) discuss the evidence of a positive co-movement between corporate and sovereign interest rates. Bevilaqua, Hale, and Tallman (2020) document that globally there is an association between sovereign spreads and corporate spreads of almost 1-to-1 during tranquil periods, and that while this association falls during periods of unusually high sovereign yields, it remains large at about 0.5. See also Agea and Celasum (2009) and Corsetti and others (2010).

[3] Fiscal space in this annex is defined as the government's budgetary flexibility in its spending choices without undermining fiscal sustainability, i.e., without generating a high risk of default.

space is already tight due to low tax revenues, high initial debt, or low creditworthiness (high spreads), increasing public investment implies either cutting public consumption (which is valued in the utility function), or the need to raise distortionary taxes or issue more government debt. Because cutting public consumption or raising distortionary tax rates reduce the welfare and growth benefits of the investment strategy, default becomes more tempting, especially if adverse macroeconomic shocks take place or are expected to take place. Consequently, default risk increases.[4]

These two opposite effects of investment on fiscal sustainability (higher TFP growth and thus future tax revenues, but also higher debt or lower private or public consumption and therefore stronger incentives to default) raise the possibility that investment strategies that are based on poor projects (with low rates of return), that are too costly (because of low public investment efficiency) or that create large financing needs, can lead to higher sovereign spreads. Because an increase in sovereign spreads results in an increase in firms financing costs,[5] some crowding out of private production takes place, reducing the growth benefit of public investment. A sufficiently large crowding out of the private sector can further tighten fiscal space, as the debt-to-GDP ratio would be larger and tax revenues would be lower than they would have been otherwise.

However, if the positive effect of public investment on the economy's repayment capacity dominates, the public investment strategy succeeds at crowding in the private sector, as spreads remain relatively stable and higher TFP crowds in the private sector, resulting in larger GDP expansions (larger "multiplier").

C. Quantitative Analysis

The model is calibrated for two archetypical economies: a developing economy facing persistent TFP shocks with large real business cycle fluctuations that result in high levels of macroeconomic volatility; and an advanced economy with higher initial levels of public capital, lower macroeconomic volatility, higher efficiency in the conversion of public investment into capital goods (high "public investment efficiency") [6], and stronger enforcement of debt obligations. The model is calibrated at a quarterly frequency using selected standard parameters from the literature and others chosen to match some targets of the economies under study and summarized in Online Annex Table 2.1.1. The model is used to compare three alternative strategies : (i) a *gradual* scaling up with public investment increasing 1 percent of GDP per year above its initial level during the next 20 years; (ii) a *fast* scaling up with the increase being 3 percent of GDP per year; (iii) an *aggressive* scaling up in which public investment increases by 4 percent of GDP per year. The results of the model are the average of 1,000 Monte Carlo simulations.

D. Results

Consistent with the previous literature, the findings of this annex emphasize that the initial stocks of public capital, the rates of return of projects, and the efficiency and transparency of the practices with which public investment projects are chosen and implemented are key factors to consider when deciding the public investment strategy (Chaterjee, Sakoulis, and Turnovsky 2003; Cavallo and Daude 2011; Buffie and others 2012; Izquierdo and others 2019). But beyond those aspects, the findings of this analysis

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[4] When deciding whether to default or not, the government compares the benefits of paying the debt to its costs. For high levels of taxes or low levels of social spending, debt repayment becomes very costly in terms of short-term welfare.

[5] Bianchi, Lizarazo and Sapriza (2014) present a model in which sovereign and corporate spreads are endogenously positively correlated due to the impact that business cycles have simultaneously on sovereign spreads and banks profitability and to the existence of implicit guarantees from the fiscal sector to the financial sector.

[6] Effective investment refers to that which translates into higher public capital. The model captures this idea by having a modified law of movement for capital, $K_{t+1}^{G} = \varepsilon I_t^G + (1-\delta)K_t^G$, where $0 < \varepsilon < 1$ measures the efficiency of the public investment process.

suggest that the feasibility of a scaling up strategy eventually depends on macroeconomic factors like the availability of fiscal space, whether monetary policy can stabilize risk premia,[7] and the overall macroeconomic volatility in the economy (e.g. the economy's vulnerability to supply, demand or terms of trade shocks). In addition, the magnitude of the increase in public investment and financing needs, which may exacerbate the vulnerability to macroeconomic shocks, are also crucial.

Advanced economies with historically low and stable interest rates are likely to see high short-term multipliers from investment surges, even when such surges are sizable (Online Annex Figure 2.1.2). However, for countries with limited fiscal space, and where monetary policy cannot stabilize sovereign risk premia, borrowing to invest can increase debt vulnerabilities, boost precautionary savings (as households and business become aware of the higher degree of economic uncertainty resulting from higher debt levels), and risk premia, which would reduce the benefits of such a strategy. Indeed, fiscal multipliers in high-debt economies tend to be low or even negative (Ilzetzki, Mendoza, and Végh 2013).

A strategy of a *gradual* scaling up of public investment may be more effective than faster strategies. Increasing public investment by 1 percent of GDP per year for the next 20 years (a *gradual* scaling up) leads to an increase in financing costs of 250 basis points, whereas a *fast* scaling up would increase financing costs by about 350 basis points, and an *aggressive* scaling up would increase financing costs by about 950 basis points (Online Annex Figure 2.1.1).[8] Even though public investment exhibits the same technological returns for all investment strategies, higher financing costs result in public investment partially crowding out private economic activity, as corporate interest rates move in tandem with sovereign rates, halving public investment multipliers in the archetypical emerging markets and frontier low-income countries under the fast and aggressive strategies. Because of the potential for such crowding out, the higher long-term public levels of capital of the *fast* and *aggressive* investment strategies do not translate one-to-one into higher average wages and employment: wages in the *gradual* strategy are only slightly lower than in the *fast* strategy, and are somewhat higher than in the *aggressive* strategy. Nevertheless, scaling up public investment remains a worthy strategy: in the long run, GDP is 10 percent higher in the *gradual* scaling up than in the baseline (12 percent under the *fast* scaling-up scenario) and welfare is 17 percent higher, in equivalent consumption units (19 percent higher for the *fast* scaling-up scenario). Other nonproductive or non-social spending increases would have even smaller multipliers because they would amplify the existing debt vulnerabilities without having a countervailing impact on either the economy's present or future capacity to repay or the ability of fiscal policy to reduce private consumption volatility (and in this way maintain households' support for debt servicing).[9]

The non-linear response of spreads and multiplier to different magnitudes of the scaling up (Online Annex Figure 2.1.1) illustrates one of the points discussed in the previous section. If the first round increase in spreads is sufficiently large, the crowding out of the private sector will dominate the effect of a higher expected public capital level on the capacity of the government to repay its debt, increasing the risk of default (debt-to-GDP ratios are higher and tax revenues are lower). Sovereign and corporate spreads increase further, crowding out private activity and amplifying debt vulnerabilities. The strength of this mechanism is shown in Online Annex Figure 2.1.2. The effect is stronger for faster surges in public investment. The sizable negative interaction between economic conditions and financing conditions

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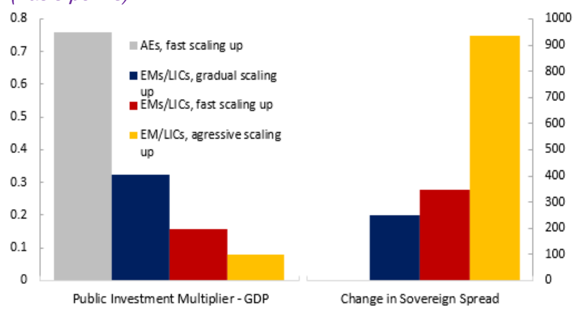
[7] In the context of the model, this refers to the ability of the government to manage interest rates.

[8] In the model, for the case of a gradual *scaling up* each additional 100 basis points of spreads increase debt servicing costs by 0.5 percent of GDP on average per year. For faster investment strategies, each extra 100 basis points of spreads generate a larger increase in debt servicing costs.

[9] In the model, the main benefit of servicing the debt and maintaining market access is the ability to smooth consumption (reduce consumption volatility) through international risk sharing.

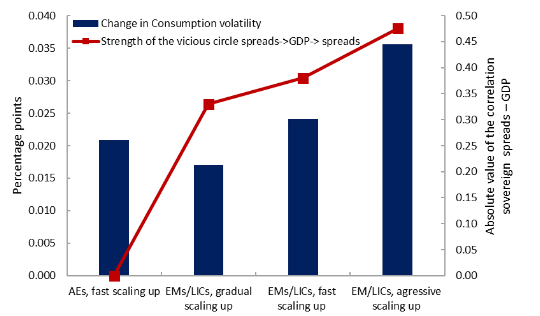
during periods of *fast* and *aggressive* investment surges risks creating a vicious circle between a high debt burden and high interest rates, thus reversing progress in strengthening fiscal policy countercyclicality (Frankel and others 2011).

Online Annex Figure 2.1.1. Response of Spreads and Multipliers to Different Strategies, by Type of Economy
(Basis points)



Source: IMF staff calculations.
Note: AEs = advanced economies; EMs = emerging markets; LIC: low-income countries.

Online Annex Figure 2.1.2. Consumption Volatility and Vicious Circle between Spreads and GDP



Source: IMF staff calculations.
Note: The strength of the vicious circle between spreads and GDP is measured using the absolute value of the correlation spreads to GDP. A high value for this variable implies a more substantial negative effect from spreads in the GDP and from the GDP back into the spreads. AEs = advanced economies; EMs = emerging markets; LIC = low-income countries.

Faster scaling-up strategies, because of their higher financing requirements and their implied effect on fiscal risks, increase consumption volatility (Figure 2.1.2), generating a steeper increase in households' precautionary savings—especially during the initial phases of the scaling up—which negatively impacts welfare and further reduces the usefulness of maintaining market access for consumption smoothing, making default more tempting.

The model also shows that developing countries with levels of debt above 60 percent of GDP see their sovereign spreads increase by more than economies with lower initial levels of debt (from already higher levels of spreads), even when the scaling up is *gradual* (Online Annex Figure 2.1.3). For these economies, multipliers are smaller, and they are 2.5 percent more likely to have output realizations below two standard deviations from the mean of the scaling-up period (17.3 percent vs. 14.5 percent for lower-debt economies). The intuition of this result is clear: a higher initial degree of debt vulnerability gets amplified by the new issuance of debt to finance investment, spreads climb further and the negative interaction between spreads and GDP growth grows more powerful.

The stronger capacity to repay debt of countries with higher initial levels of public capital translates into lower and more stable risk premia and into higher multipliers (Online Annex Figure 2.1.1 and Online Annex Figure 2.1.3), even though the marginal productivity of public capital is higher when capital is more scarce. This result implies that when debt vulnerabilities are an issue, high rates of return for investment projects might not guarantee market financing at low costs. It also suggests that in the long term, an additional benefit of effective higher public investment is to enhance countries' access to credit markets.

How investment is financed also matters. For countries with access to financing at low costs, fiscal multipliers tend to be higher if public investment is financed with debt (see the October 2014 *World Economic Outlook*). However, for countries whose access to market financing is very sensitive to the fiscal situation, raising tax rates may mitigate the increase in risk premia, allowing fiscal multipliers to be larger

(Online Annex Figure 2.1.3). The effect tends to be especially important when deciding to follow *fast* or *aggressive* public investment scaling-up strategies.

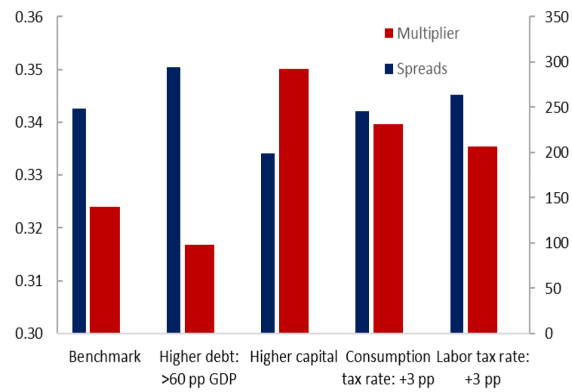
The sensitivity of risk premia to the strategy also depends on the macroeconomic risks each country faces. The model shows that the impact of scaling up public investment on financing costs is smaller for countries with low or moderate levels of macroeconomic volatility, independently of the speed of the scaling up of investment. For emerging markets and frontier low-income countries that exhibit high macroeconomic volatility, a *gradual* scaling up remains better than a *faster* or *aggressive* scaling up.

The model also shows that when corporate spreads respond less to the financing of the investment surge (either because of monetary policy actions or because financing is not on market terms), the crowding out of the private sector is weaker and the growth impact (and the multiplier) of investment is larger; as a result, the debt-to-GDP ratio grows less, and the lower implied debt vulnerabilities result in muted second round increases in sovereign spreads. (Online Annex Figure 2.1.4).

Finally, an important question is whether markets consider that the investment strategy credibly builds assets of quality. For this, the permanence of the investment effort also matters (Blöchliger, Song, and Sutherland 2012). Often, governments faced with fiscal constraints halt or reverse investment plans (Online Annex Figure 2.1.5). This may be an optimal response in the short term because it softens the impact of negative shocks by allowing reprioritization of public expenditure away from capital expenditure and towards social spending and other basic needs (health, education, wages), which have an immediate value for

Online Annex Figure 2.1.3. Sensitivity to Initial Conditions and Financing

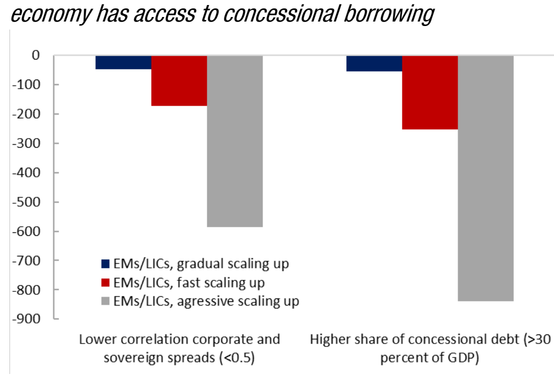
Multipliers (spreads) are lower (higher) when debt is high, and higher (lower) when initial capital or tax rates are high.



Source: IMF staff calculations.
Note: The LHS y-axis measures the public investment multiplier (with values in the range of 0.31 to 0.35). The RH y-axis measures spreads, shown in basis points. pp: percentage points.

Online Annex Figure 2.1.4. Sensitivity of Spreads to Capacity to Finance Debt

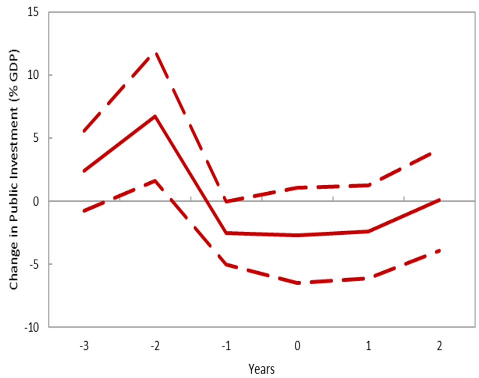
In equilibrium sovereign spreads are lower if the correlation between corporate and sovereign spreads is low or if the economy has access to concessional borrowing



Source: IMF estimates.
Note: The figure shows the differences between the spreads in the benchmark economy and (1) the economy with a lower correlation between sovereign and corporate spreads and (2) the economy with higher share of concessional debt. For gradual scaling up, if monetary policy successfully reduces the correlation of corporate and sovereign spreads, the increase in sovereign spreads resulting from the scaling up is 45 basis point lower than in the benchmark. EMs = emerging markets; LIC = low-income countries.

Online Annex Figure 2.1.5. Fiscal Crises and Public Investment in Advanced Economies and Emerging Markets

(Percent of GDP)



Sources: Gerling and others 2017; IMF, Capital Stock database; and IMF staff estimates.
Note: The *y*-axis shows coefficients of the regression of changes in public-investment-to-GDP ratios on the occurrences of fiscal crises, as defined by Gerling and others (2017). Time periods are in years on the *x*-axis; 0 indicates the beginning of the crisis.

welfare.[10] In that case, the long-term benefits of the strategy are not realized, and only the costs of higher debt remain; this risk is priced by markets, raising financing costs. To ensure the credibility of a plan of sustained investments and to mitigate the impact on financing costs, governments need to ensure that the plan's macroeconomic and financial assumptions are realistic and communicated transparently. Medium-term budget frameworks can help translate long-term aspirations into concrete budget decisions. A variety of public financial management practices can also contribute to protecting capital appropriations, such as setting ceilings on transfers of appropriations from capital to current spending and giving priority to active projects rather than new ones.

[10] Gordon and Guerrón-Quintana (2013) and Asonuma and Joo (2019) also find that in the presence of macroeconomic uncertainty, investment strategies (private and public) have a built-in embedded time inconsistency: Ex-ante investment expands productive capacity, but ex-post, when a negative shock hits and borrowing becomes too expensive, reducing investment becomes an effective way to mitigate the welfare cost of such shock.

Online Annex Table 2.1.1 Calibration of the Model

Parameter Name	Value	Target	Reference
Risk aversion	2		Standard value in the Real Business Cycle literature.
Labor supply elasticity	2.2		Mendoza and Yue (2012).
Discount factor	0.88	EMs/LICs' sovereign default probability in a range of 0.5 to 1.5 percent.	Mendoza and Yue (2012)
World free interest rate	0.01		Standard value in the Real Business Cycle literature.
Probability of re-entry credit markets after	0.125	8 to 10 quarters of exclusion from credit markets after default.	Value consistent with estimates reported by empirical sovereign debt literature (Asonuma and Trebesch 2015; Gelos, Sahay, and Sandleris 2011)
Cost of default	Calibrated to match a target	Initial average debt-to-GDP ratio of 45 percent.	Asymmetric cost of default as in Chatterjee and Eyigoungour (2012)
Correlation of sovereign and corporate spreads	1 for spreads below 1,000 basis points, 0 otherwise		Bevilaqua, Hale, and Tallman (2020) report that worldwide, the correlation is close to 1 in tranquil periods and close to 0.5 in periods of fiscal crises
Intermediate goods participation on gross output	0.576	Average for EMs in Eastern Europe	The UN Statistics Division's latest available data for Bulgaria, Czechia, Estonia, Hungary, Poland, and Serbia
Elasticity of substitution of importable and domestic intermediate goods	1.25		Value in the range of possible estimates (McDaniel and Balisteri 2002; Feenstra and others 2018)
Share of importable inputs in the composite intermediate good	0.5	Calibrated to match a 0.23 ratio of imported inputs to total intermediate goods.	See Mendoza and Yue (2012) for a discussion of the findings in Campa and Goldberg (2006)
Share of importable inputs subject to an advanced capital constraint	0.7	Calibrated to match a working-capital-to-GDP ratio of 2 percent	Mendoza and Yue (2012) find this ratio to be 6 percent for Argentina; a more conservative value prevents overstating the impact of financing costs on public investment multipliers
Labor participation on GDP	0.64		In the range of standard values used in the economic literature
Capital participation on GDP	0.36		In the range of standard values used in the economic literature
Private-capital (fixed)-to-output ratio	3		In the range of standard values used in the economic literature
Average public capital AEs before scaling up	Calibrated to match a target	Calibrated to match an initial ratio between average GDP per capita for AEs vs. EMs of 3.	Value similar to those seen in the data for EMs vs. AEs (The OECD data for 2019: ratio for the GDP per rcapita of Australia vs. Colombia, Spain vs. Indonesia, United States vs. Mexico, and Luxembourg vs. Lithuania)
Productivity of public capital	Calibrated to match a target	Calibrated to a productivity of public capital above 15 percent per year	Buffie and others (2012) discuss evidence of large returns to infrastructure in developing economies (possibly in the range of 15 to 30 percent yearly)
Persistence of TFP shocks	0.88		In the range of values used in the sovereign debt literature
Volatility of TFP shocks	0.0223 EMs/LICs 0.009 AEs		In the range of values used in the sovereign debt literature

Source: Prepared by the author.

Note: AE: advanced economy; EM: emerging market; LIC: low-income country; OECD: Organisation for Economic Co-operation and Development; TFP: total factor productivity.

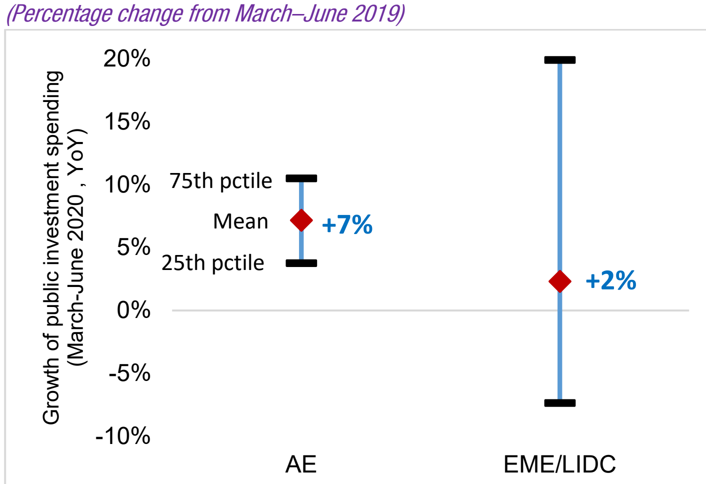
Online Annex 2.2. Assessing the Impact of the COVID-19 Crisis on Monthly Investment Budgets[1]

Examining investment outturn data over the first few months of 2020 can shed light on the impact of the COVID-19 pandemic on public investment. While the fact that public investment is one of the major casualties in countries experiencing a fiscal crisis has been well established and documented ex post (see Roubini and Sachs, 1989 ; Hicks, 1991), the real-time impact of a major fiscal or financial crisis on public investment using higher frequency execution indicators has received less attention.

For this purpose, data on monthly budget execution for the first few months of 2020 is collected for a sample of 13 countries, including advanced economies, emerging market developing economies, and low-income developing countries (Online Annex Figure 2.2.1)[2] and separated out by the economic classification of spending. The analysis focuses on the period from March to June, as the COVID-19 pandemic started to have a strong impact outside China during the first half of March 2020

Online Annex Figure 2.2.1. Public Investment Spending, March–June 2020

(Percentage change from March–June 2019)



Source: IMF staff estimates based on monthly public investment spending figures.
Note: The figure shows the distribution of monthly public investment execution, deflated by the 2019 end-of-year consumer price index. Averages (square) are nonweighted. AE = advanced economies; EME = emerging market economies; LIDC: low-income developing countries; YoY = year- over-year.

In advanced economies, over the first few months of 2020, public investment was quite dynamic compared to the year before (a growth rate of 7 percent, year-over-year). One explanation could be that advanced economies, which did not face liquidity constraints (thanks in particular to exceptional central bank interventions) may have tried to frontload investment spending in order to mitigate the impact of the coming crisis. They could take advantage of good conditions for a wide variety of public investments, for instance low traffic facilitating road, rail, and airport works, and low energy consumption facilitating electricity network improvements.

In emerging market developing economies and low-income developing countries, however, the situation was more mixed. This could be attributed to disruptions induced by COVID-19 but also to precautionary measures to preserve fiscal space in the face of the large impact of the pandemic on revenues and the overall fiscal balance. As a result, investment increased only by 2 percent year-over-year, on average for this group of countries, with investment falling for almost half of the sample.

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[1] This annex was prepared by Claude Wendling and Sureni Weerathunga of the Fiscal Affairs Department.

[2] The sample was composed of the following countries: for advanced economies, *France, United Kingdom, Portugal*, and *Germany*; for emerging market developing economies, *South Africa, India, Maldives, Albania, Mexico,* and *Nepal*; and for low-income developing economies, *Côte d'Ivoire, Burkina Faso*, and *Afghanistan*.

There are of course limitations to this exercise. These include (i) the small size of the sample, especially for low-income developing countries where monthly budget execution data are seldom available in a public, timely and reliable manner; (ii) the institutional coverage, which is limited in most cases to the central government whereas a sizable part of public investment may be by subnational governments, extra budgetary funds, or state-owned enterprises; (iii) heterogeneity in the notion of "public investment" as captured in the monthly execution bulletins, where the economic classification may not be fully in line with the IMF's Government Financial Statistics standards and may reflect country-specific practices; and (iv) the fact that some of the variation in public investment captured in the analysis may reflect trends that are unrelated to COVID-19, such as the impact of a growth in investment spending that may have been planned well before the COVID-19 pandemic.

However, closer monitoring of budget execution data can clearly give early warning signals useful for a government planning and implementing an investment strategy.

Online Annex 2.3. Maintaining Quality When Scaling Up Public Investment[1]

This Annex explains the analysis of World Bank project-level information on delays and cost overruns. Although there exists a literature looking at the micro and macro determinants of project success–as measured by qualitative evaluations (Denizer and others 2013; Presbitero 2016)–less has been written on the mechanisms explaining project outcomes, such as time delays and cost overruns (although see Flyvbjerg 2009; Collier, Kirchberger, and Söderbom 2016; Gurara and others 2020 on cost overruns).

A. Data

The main data are from the World Bank investment projects matched with the World Bank's Independent Evaluation Group project evaluation data.[2] For about 3,000 projects approved since 2000 in more than 110 emerging markets and developing countries, it is possible to compute measures of time delays and cost overruns from information available in individual project documents. Text search analysis facilitated compiling information on the length and cost of individual projects, measured both at the time of approval and at completion. Delays are defined as the difference between the actual project completion date and the completion date anticipated at the beginning of the project, scaled by project length (all measured in days). Cost overrun is the difference between the actual project cost and that at appraisal, as a ratio of project cost at appraisal.

Comparing the actual final cost and project length with those estimated at the start of each project shows that delays and cost overruns are very frequent and, often, quite substantial. This is not unique to World Bank projects, as there is evidence showing similar trends and numbers for other multilateral institutions (Ahsan and Gunawan, 2010; Serebrisky and others 2017) and more generally for investment projects, especially in infrastructure (Flyvbjerg 2009).

Data on cost overruns indicate that almost 40 percent of the projects cost more than the estimated appraisal cost, with a median cost escalation of about 19 percent, and that more than 10 percent of the projects cost more than twice the original amount.[3] There are large differences across sectors, with water, transportation and social protection having a high share of projects with cost overruns and a median cost escalation substantially larger than in other sectors. Comparing emerging markets with low-income countries shows that time delays and cost overruns are more prominent in poorer countries.

The data also show that about three-quarters of projects are completed in a timeframe longer than projected. The median delay is almost 30 percent of the original length, with more than 10 percent of the

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[1] Prepared by Andrea F. Presbitero from the Research Department. Text mining on Independent Evaluation Group project-level reports by Dominique Guillaume and Jorge Martinez is gratefully acknowledged.

[2] Data are available at https://datacatalog.worldbank.org/dataset/world-bank-projects-operations (version as of 8 April 8 2020) and https://finances.worldbank.org/Other/IEG-World-Bank-Project-Performance-Ratings/rq9d-pctf (version as of 4 February 2020). Individual project documents are also available on the World Bank website at https://projects.worldbank.org/. While focusing exclusively on World Bank projects may generate concerns about the validity of the results in a broader context, there are reasons that can make the findings more general. First, the World Bank is one of the largest donors, and its model for selecting, financing and assessing projects is the most common one across aid agencies (Denizer and others 2013). Second, the statistics on cost overruns and time delays are similar to those from other donors. Finally, previous analyses using projects funded by the World Bank and other donors have shown similar patterns across funding agencies (Briggs 2019; Bulman and others 2017; Caselli and Presbitero 2020).

[3] Consistent with this evidence, Serebrisky and others (2017) show that 53 percent of World Bank infrastructure projects suffered cost overruns, and the share is even higher (82 percent) for those financed by the Inter-American Development Bank. Similarly, 86 percent of sampled development projects financed by the Asian Development Bank experienced marked cost overruns (Ahsan and Gunawan 2010). Flyvbjerg and others (2003) look at project-level data from 20 countries and find evidence of cost escalation in 86 percent of projects, where actual costs exceeded estimated cost by an average of 28 percent.

projects completed with a delay of at least 50 percent of the original length. The distribution across sectors points to some differences, especially in the case of projects in the energy and mining sector, which tend to be delayed more.

B. The Empirical Model

To look at the drivers of project delays, this annex estimates the following model:

$$Delay_{jct} = PROJECT_{jt} + MACRO_{ct} + \tau_t + \varphi_j + r_c + LIDC_c + \varepsilon_{jct}, \quad (1)$$

where *Delay* is the time delay of project *j*, approved in year *t* in country *c*. The vector of project-level characteristics (*PROJECT*) includes (1) size, measured by the logarithm of the dollar amount of project cost; (2) length, computed as the difference between the end and approval date; (3) the time between project completion and evaluation (both variables are measured in days); (4) the share of funding provided through grants; (5) the portion of the largest share of the project assigned to a single sector (multiplied by -1, as a measure of project complexity); (6) a dummy identifying projects that have received an estimated rate of return at appraisal; and (7) a dummy to identify investment projects from adjustment loans. The macroeconomic variables (*MACRO*) include the log of per capita real GDP (measured in the year of project approval) and the average real GDP growth rate over the length of the project. The two macroeconomic variables of most interest are a measure of public investment scaling up and government effectiveness. The former is defined as the difference between the public investment-to-GDP ratio and its past 10-year average. This variable is also averaged over the length of the project.[4] Government effectiveness is taken from the World Governance Indicators and measured in the year of project approval. For robustness, institutional quality is also measured by an index of regulatory quality. The descriptive statistics for the regression sample are shown in Online Annex Table 2.3.1.

Online Annex Table 2.3.1. Descriptive Statistics

Variable	No. of Obs.	Mean	St. Dev.	Min.	Max.
Time delays	2,203	23.6	17.7	0.0	61.1
Cost overrun	2,203	4.2	38.9	-71.3	128.5
Project size	2,203	17.9	1.4	14.1	24.0
Project length	2,203	2210	879	180	5402
Evaluation length	2,203	614	479	38	3846
Project complexity	2,203	-63.0	26.7	-100.0	-1.0
Grant financing (%)	2,203	7.6	24.8	0.0	100.0
Expected rate or return at appraisal (0/1)	2,203	0.2	0.4	0.0	1.0
Public investment scaling up	2,203	0.3	2.1	-9.4	8.2
Public investment scaling up, initial	2,183	0.3	2.6	-12.5	11.8
Government effectiveness	2,203	-4.4	5.0	-20.4	14.8
Regulatory quality	2,202	-3.8	5.1	-21.0	15.4
GDP per capita (logs)	2,203	7.7	3.3	-7.8	15.9
Real GDP growth	2,203	5.4	2.7	-7.1	31.2

Source: IMF staff estimates based on information from the World Bank' Independent Evaluation Group and project-level Implementation Completion Reports.

The set of fixed effects includes year, sectors, regions, and country group (splitting low-income developing countries and emerging markets). The most restrictive specification also includes year *x* sector fixed effects to allow for time-varying sector-specific unobserved shocks that may affect the timing of

[4] Data for public investment, as well as for GDP, are from the World Economic Outlook database. Results are robust to measuring the scaling-up variable in the project's year of approval (see Online Annex Table 2. 3.2).

project execution. Standard errors are clustered at the country level to allow for within-country serial correlation of the residuals, and also to match the fact that the key explanatory variables are measured at the country level.

C. Results

The baseline results are reported in Online Annex Table 2.3.2, while some extensions and robustness exercises are shown in Online Annex Table 2.3.3. In interpreting these results, an important caveat, standard to this type of analysis, is that most of the variation in project outcomes is project-specific (and often unobservable). This can be seen observing the value of the R-squared that, even including the largest set of fixed effects and the macro controls, is about 0.36 (and increases to 0.38 adding country fixed effects (see columns 3 and 7 in Online Annex Table 2.3.2).

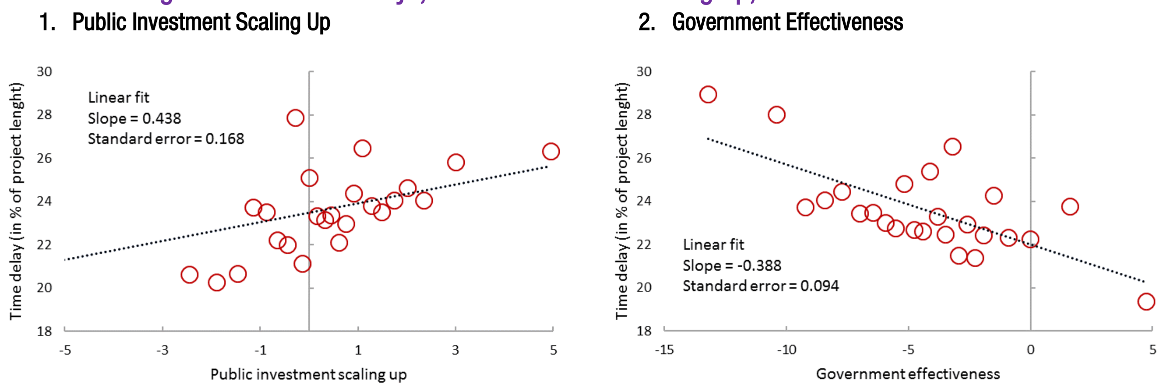
Online Annex Table 2.3.2. Micro and Macro Drivers of Project Delays

Dep. Var.: Time Delays	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Project size	-1.3219***	-1.0865***	-0.4411	-1.0176***	-0.9355**	-0.8933**	-0.7337**
	(0.439)	(0.355)	(0.380)	(0.363)	(0.379)	(0.375)	(0.344)
Project length	0.0136***	0.0136***	0.0133***	0.0135***	0.0134***	0.0135***	0.0135***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Evaluation length	-0.0007	-0.0006	-0.0008	-0.0006	-0.0005	-0.0005	-0.0003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Project complexity	-0.0208*	-0.0230**	-0.0282***	-0.0238**	-0.0257**	-0.0259**	-0.0311**
	(0.011)	(0.011)	(0.010)	(0.011)	(0.011)	(0.011)	(0.013)
Grant financing (%)	0.1410***	0.1502***	0.1352***	0.1520***	0.1442***	0.1461***	0.1475***
	(0.024)	(0.024)	(0.021)	(0.024)	(0.022)	(0.022)	(0.022)
Expected rate or return at appraisal (0/1)	-1.7074**	-1.7648**	-1.7688**	-1.6652**	-1.7136**	-1.6604**	-1.4792*
	(0.763)	(0.758)	(0.713)	(0.743)	(0.744)	(0.736)	(0.779)
Public investment scaling up				0.4377**		0.3624**	0.3964**
				(0.168)		(0.172)	(0.181)
GDP per capita (logs)				0.0118	0.0113	0.0073	-0.0199
				(0.183)	(0.169)	(0.168)	(0.170)
Real GDP growth				-0.3010*	-0.3168**	-0.3603**	-0.3076*
				(0.173)	(0.157)	(0.156)	(0.159)
Government effectiveness					-0.3876***	-0.3677***	-0.3997***
					(0.094)	(0.096)	(0.098)
Observations	2,203	2,203	2,198	2,203	2,203	2,203	2,186
Country FE	No	No	Yes	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	-
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	-
Sector*Year FE	No	No	No	No	No	No	Yes
Region FE	No	Yes	-	Yes	Yes	Yes	Yes
LIDC FE	No	Yes	-	Yes	Yes	Yes	Yes
Sample	All	All	All	All	All	All	All
R2adj	0.3411	0.3488	0.3756	0.3514	0.3561	0.3575	0.3611

Source: IMF staff estimates.
Note: The table reports the ordinary least squares regression of equation (1) in which the dependent variable is the time delay—measured as the difference between the actual project completion date and the one estimated at the beginning of the project, scaled by project length—of project *j*, approved in year *t* in country *c*. Standard errors are clustered at the country level. FE: fixed effect; LIDC: low-income ceveloping country.

Starting from project-specific characteristics, two main findings stand out. First, projects that are completely funded by grants suffer delays that are 14 percentage points longer than projects funded without grants. This evidence points to the critical role played by country ownership and the involvement of local authorities for project success and for the effectiveness of a scaling-up of investment (Bourguignon and Sundberg 2007; Edwards 2015). This result may also suggest that risky projects—which could be more prone to delays—are more likely to funded by grants, while safer projects, which are more likely to generate a stable stream of revenues, are funded by loans. Second, projects for which there has been an assessment of the expected rate of return at appraisal show shorter delays. To the extent that receiving an expected rate of return is a proxy for careful project preparation, this result suggests that ex-ante project design matters for project outcomes. A counterintuitive result is that larger projects and more complex projects (as measured by the number of sectors a project spans) have shorter delays.[5] This result could signal that more complex projects are better planned and designed.[6] Finally, longer projects are also more likely to finish with longer delays (measured in proportion to their original timeline). All the results on project-level variables, apart from size, are robust to the inclusion of a wide range of fixed effects, including those at the country level.

Online Annex Figure 2.3.1. Time Delays, Public Investment Scaling Up, and Governance



Source: IMF staff estimates.
Note: Both panels are binned scatterplots. A regression of time delay against public investment scaling up (panel 1) or government effectiveness (panel 2)—controlling for per capital GDP (in logs), real GDP growth, a large set of project-level characteristics, and year, sector, region and country group fixed effects—gives a coefficient on the scale-up variable of +0.44 (panel 1) and of the government effectiveness variable of -0.39 (panel 2). These results correspond to columns 4 and 5 in Online Annex Table 2.3.2. To generate the binned scatterplot, starting from the sample of 2,203 projects, the time delay (y–axis) and the scale-up variable (panel 1) or government effectiveness (panel 2) (*x*–axis) are regressed against controls and fixed effects. The *x*-residuals are grouped into 25 equal-sized bins. The panels then plot, for each bin, the mean of the time delay, within each bin, holding the controls constant. The solid line is the linear fit of the ordinary least squares regression of the y-residuals on the x-residuals.

The second step of the analysis zooms in on the role of selected macroeconomic variables that could influence time delays. The identification is in the cross-section, given the limited within-country variability over the sample period. A first result is that project delays increase with the size of the scale up of public investment, defined as the difference between actual public investment and its average level in the previous 10-year period (column 4 in Online Annex Table 2.3.2 and Online Annex Figure 2.3.1, panel 1). A 3 percentage points increase in the public investment-to-GDP ratio with respect to its average in the previous 10-year period is associated with an increase in delays of 1.1 percentage points. This result is consistent with the presence of absorptive capacity constraints, because when public investment is scaled up substantially (and too fast), the design and execution of several projects could be slowed down by the lack of resources and skills. While the size of this effect is relatively contained, it is worth noting that delays can be longer in response to a fast scaling up for projects that do not rely on guaranteed donor financing but are funded by more volatile financing. The effect of scaling up investment on cost overruns, based on a similar multivariate regression focusing on cost overruns, is also presented in Figure 2.6 of the main text.

[5] However, the negative coefficient on project size turns insignificant once country fixed effects are included.

[6] However, the literature on megaprojects shows that time and cost overruns are quite substantial (Ansar and others 2014; Callegari and others 2018).

The second result is that, even when controlling for a country's per capita GDP and growth, countries with better governance are able to complete projects with shorter delays (column 5 in Online Annex Table 2.3.2 and Online Annex Figure 2.3.1, panel 2). Moving from the 75th to the 25th percentile of the distribution of measure of government effectiveness is associated with a decline in delays of about 2.6 percentage points—a sizable effect.[7] The two main results on public investment scaling up and governance hold when adding the two variables together and even when controlling for year *x* sector fixed effects (columns 6–7 in Online Annex Table 2.3.2). Finally, results also show delays are longer for investment undertaken in periods of low growth: 2 percent lower growth is associated with a 0.7 percentage point increase in delays.

Splitting the sample between low-income developing countries and emerging markets (Online Annex Table 2.3.3, columns 1-2) shows that the scale up of public investment is significant only in the emerging market sample (where the effect is stronger, a 2.5 percentage point increase in delays following a 3 percentage points increase in the public investment to-GDP ratio with respect to its historical average), while there is no association in low-income developing countries–possibly because project delays tend to be already larger in low-income countries. Column 3 limits the sample to all projects started up to 2011 in order to address the concern that looking at the latest years may generate a bias in the results, given that projects with longer delays may not yet show in the data. Finally, the last two columns show that results are robust to an alternative definition of institutional quality (for example, regulatory quality) and to measuring the scaling-up variable in the year of project approval.

[7] Serebrisky and others (2017) show a similar association between shorter delays and a higher government effectiveness score in a sample of Latin American countries.

Online Annex Table 2.3.3. Micro and Macro Drivers of Project Delays: Robustness

Dep. Var.: Time Overrun	(1)	(2)	(3)	(4)	(5)
Project size	-0.5425	-1.4853**	-0.8094**	-0.9831***	-0.9177**
	(0.479)	(0.578)	(0.393)	(0.359)	(0.375)
Project length	0.0134***	0.0137***	0.0136***	0.0135***	0.0135***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Evaluation length	-0.0002	-0.0018	-0.0005	-0.0004	-0.0005
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Project complexity	-0.0242*	-0.0248	-0.0251**	-0.0252**	-0.0257**
	(0.013)	(0.019)	(0.011)	(0.011)	(0.011)
Grant financing (%)	0.1538***	0.1350***	0.1578***	0.1479***	0.1457***
	(0.032)	(0.029)	(0.025)	(0.023)	(0.022)
Expected rate or return at appraisal (0/1)	-1.0614	-2.7778***	-1.5323**	-1.6047**	-1.5761**
	(1.065)	(1.002)	(0.746)	(0.731)	(0.753)
Public investment scaling up	0.8187***	0.0350	0.3010*	0.4005**	
	(0.258)	(0.223)	(0.180)	(0.173)	
GDP per capita (logs)	0.1137	-0.2823	-0.0252	0.0151	0.0381
	(0.214)	(0.241)	(0.177)	(0.178)	(0.170)
Real GDP growth	-0.3126	-0.3376	-0.3371**	-0.4038**	-0.3242**
	(0.189)	(0.269)	(0.157)	(0.157)	(0.153)
Government effectiveness	-0.3462**	-0.3413**	-0.3891***		-0.3703***
	(0.138)	(0.130)	(0.102)		(0.101)
Regulatory quality				-0.3213***	
				(0.114)	
Public investment scaling up, initial					0.2615**
					(0.132)
Observations	1,275	927	2,038	2,202	2,183
Country FE	No	No	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes
Sector*Year FE	No	No	No	No	No
Region FE	Yes	Yes	Yes	Yes	Yes
LIDC FE	-	-	Yes	Yes	Yes
Sample	EMDEs	LIDCs	up to 2011	All	All
R2adj	0.3601	0.3650	0.3412	0.3553	0.3558

Source: IMF staff estimates.

Notes: The table reports the ordinary least squares regression of equation (1) in which the dependent variable is the time delay—measured as the difference between the actual project completion date and the one estimated at the beginning of the project, scaled by project length—of project j, approved in year t in country c. In columns 1 and 2, the sample is limited to emerging market and low-income developing economies, respectively. In column 3 the sample is limited to projects approved up to 2011. In column 5, the public investment scaling-up variable is measured in the year of project approval, rather than averaged over the length of the project. Standard errors are clustered at the country level. EMDE: emerging market developing economy; FE: fixed effect; LIDC: low-income developing country.

Online Annex 2.4. The Direct Labor Impact of Public Investment[1]

A. Introduction

The global recession triggered by the COVID-19 pandemic has been particularly devastating for employment, with unemployment rising to record-high levels worldwide and 305 million full-time job losses according to the latest available estimate by the International Labour Organisation (2020). Recovery packages—in which public investment play a significant part (Auerbach and Gorodnichenko 2013b)—are often assessed by the number of jobs they create. This annex aims to quantify the direct labor impact of infrastructure development and maintenance in selected sectors: education, health, electricity, roads, and water and sanitation in a wide range of advanced, emerging, and low-income economies.[2]

Public infrastructure projects are usually performed through contractors, either state-owned or private—that is, they are rarely performed directly by the public administrations through its payroll. Every dollar spent on public investment goes to some company's revenue, which subsequently increases payroll and employment. The focus of this annex is on public investment for the post-COVID recovery (that is, phase 3 of the recovery), when social distancing is less relevant. It is worth noting, though, that public investment projects can be compatible with stricter social distancing (that is, during phase 2).

The annex contributes to the literature by covering a wide spectrum of sectors and countries, and by quantifying the labor multipliers by income groups, which can be extrapolated to all countries. A rich panel dataset of construction companies in social and physical infrastructure was assembled, based on Compustat and ORBIS, which primarily cover companies not publicly listed worldwide (that is, private and state-owned companies). Companies are filtered by industry codes (see Online Annex Table 2.4.1). The industry codes for electricity, roads, and water and sanitation are precise. For schools and hospitals, a residual industry code is used for the construction of institutional buildings that excludes housing and industrial sites.[3]

B. Data and Methodology

The span of both datasets is matched from 1999 to 2017, and revenue values are adjusted to constant 2015 US dollars using GDP deflators. Outlier observations for revenue and employment are dropped, and companies with at least five annual observations are retained to have sufficient within-company variation for fixed effects and clustering (Kézdi 2004; Wooldridge 2003) and avoid biasing the estimates by inclusion of cyclical shell companies. Limited data granularity does not allow for disentangling labor utilization in investment versus maintenance, skilled versus unskilled labor, and migrant and imported versus local labor.

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[1] This annex was prepared by Mariano Moszoro from the Fiscal Affairs Department.

[2] Sometimes the terms "public investment" and "public works" are used interchangeably. The American Public Works Association defines public works as "the combination of physical assets, management practices, policies, and personnel necessary for government to provide and sustain structures and services essential to the welfare and acceptable quality of life for its citizens" (https://www.apwa.net/MYAPWA/About/What_is_Public_Works/MyApwa/Apwa_Public/About/What_Is_Public_Works.aspx). In the definition, "provide and sustain" means both development of new and maintenance of existing infrastructure.

[3] There are no exclusive industrial codes for construction companies in education and health. That is, the classification codes contain not only schools and hospitals, but also the construction of government administrative buildings, prisons, colleges, museums, sports facilities, etc.

The resulting dataset is comprised of 47,580 observations for 5,679 firms in 41 advanced and emerging market economies. There are no data from low-income developing countries. Online Annex Table 2.4.2 presents the summary statistics of revenues and employees by income group.

Online Annex Table 2.4.1 Sectors and Industries by Data Source

Sector	Compustat (NAICS)	Orbis (CPA)
Electricity	**237130**—Power and Communication Line and Related Structures Construction	**F42.2.1**—Construction of utility projects for fluids **F42.2.2**—Construction of utility projects for electricity and telecommunications
Roads	**237310**—Highway, Street, and Bridge Construction **333120**—Construction Machinery Manufacturing (Drags, road construction and road maintenance equipment, manufacturing)	**F42.1**—Construction of roads and railways, including: **F42.1.1**—Construction of roads and motorways, **F42.1.2**—Construction of railways and underground railways, and **F42.1.3**—Construction of bridges and tunnels
Schools and hospitals	**2362**—Commercial and Institutional Building Construction	**F42.9.9**—Construction of other civil engineering projects n.e.c.
Water and Sanitation	**237110**—Water and Sewer Line and Related Structures Construction	**F42.9.1**—Construction of water projects

Source: Compustat and Orbis.
Note: NAICS is the North American Industry Classification System (cf. https://www.census.gov/eos/www/naics/) and CPA is the European Classification of Products by Activity (cf. https://ec.europa.eu/eurostat/web/cpa).

Online Annex Table 2.4.2. Summary Statistics

Advanced Economies	Obs.	Mean	Std. Dev.	Min	Max
Revenue (millions of 2015 U.S. dollars)	43,485	11.0	14.5	0.6	99.9
Employees	43,485	45.1	74.4	0.1	3340.0

Emerging Market Economies	Obs.	Mean	Std. Dev.	Min	Max
Revenue (millions of 2015 U.S. dollars)	4,095	7.7	11.8	0.0	97.9
Employees	4,095	123.4	195.0	0.2	3650.0

Source: Author's estimations based on Compustat and Orbis.
Note: This table presents the summary statistics of revenues in millions of 2015 US dollars and employment broken down by income group. The sample data are for 1999–2017, and only firms with at least five annual observations were kept.

The observations are relatively well distributed across the electricity, roads, and schools and hospital sectors (between 12,000 and 19,000 observations), with less coverage in the water and sanitation sector (approximately 1,500 observations). Despite its rich sectoral, geographic, and economic development scope at the firm level, the resulting dataset should be treated as illustrative rather than statistically representative due to selection biases in the entry dataset.

The marginal pass-through from expenditures in public investment to employment is computed by regressing employment on revenues by sector and country income group at the individual firm level.[4] The following regression is estimated:

$$L_{i,t} = \alpha + \beta_s\left[R_{i,t} \times S_i\right] + X + \varepsilon,$$

where $L_{i,t}$ and $R_{i,t}$ are the employment and revenue in firm i at time t, S_i is the vector of sector dummy variables, and X is the country (model 1) or firm (models 2–4) fixed effects. All regressions standard

[4] The straightforward average employment per unit of public expenditure or firm revenue would upwardly bias the estimations, since it would include overhead employees.

errors are clustered at the firm level. The point estimates β_s represent the change in employment per additional unit of revenue (in this case, millions of 2015 US dollars) per sector.

C. Results

Public investment is procured through state-owned and private construction companies, which then increase employment according to their needs. Online Annex Table 2.4.3 presents the results of regressions of employment on revenues in millions of 2015 US dollars. Model 1 uses pooled data with country fixed effects. Model 2 uses firm-level fixed effects, which implies that labor is sticky at the firm level.

Because the 2008–09 global financial crisis hit the construction sector particularly hard, including these years could bias the estimates. In addition, the elasticities of hiring and firing could be asymmetrical. For robustness, model 3 restricts the estimations to the years 1999–2007 and 2010–17, and model 4 computes the impact on employment for positive increases in revenue. The results are similar to those of model 2.

The coefficients are of the expected sign and predominantly statistically significant. Regression results show that the employment pass-through is higher the lower the income level. The construction of hospitals and schools is comparatively less labor-intensive in advanced economies, which points to higher standardization and investment in equipment rather than utilizing labor.

Online Annex Table 2.4.4 summarizes the main results, assuming partial "stickiness" in employment within firms, sectors, and countries (i.e., the midpoint between models 1 and 2 from Annex Table 2.4.3). The labor impact in low-income developing countries is computed as a linear extrapolation from advanced economies and emerging market economies (i.e., the job creation difference by sector between low-income developing countries and emerging market economies equals the job creation difference by sector between emerging market economies and advanced economies).

The employment impact ranges from 1.5 jobs in schools and hospitals to 3.3 jobs in electricity per $1 million of spending in advanced economies and from 8 jobs in roads to 15.2 jobs in water and sanitation in low-income developing countries. Put differently, each unit of public spending creates more direct jobs in electricity in high-income countries and more jobs in water and sanitation in low-income countries.

Calls for a green recovery post-COVID-19 have emphasized green investment could create more jobs than traditional investment (Garrett-Peltier 2017; Allan and others 2020; Coalition of Finance Ministers for Climate Action 2020). In advanced economies, job intensity is larger for green compared with traditional investment. For example, job intensity—net of job losses in traditional industries—is estimated at 5 to 10 jobs per $1 million invested in green electricity, 2.4 to 12.5 jobs in efficient new buildings like schools and hospitals, and 5.7 to 14 jobs in green water and sanitation through efficient agricultural pumps and recycling (Popp and others 2020; IEA 2020).

Online Annex Table 2.4.3. Employment Intensity in Selected Infrastructure Sectors

Advanced Economies

	(1) Pool	(2) Panel	(3) Without 2008-2009	(4) Revenue increases
Electricity	4.278***	2.363***	2.390***	2.433***
	(0.238)	(0.206)	(0.217)	(0.210)
Roads	3.124***	1.722***	1.742***	1.817***
	(0.114)	(0.128)	(0.141)	(0.142)
Schools and Hospitals	2.223***	0.850***	0.817***	0.824***
	(0.238)	(0.125)	(0.116)	(0.166)
Water and Sanitation	2.778***	1.206***	1.184***	1.153***
	(0.348)	(0.235)	(0.252)	(0.290)
Fixed effects	Country	Firm	Firm	Firm
Clustered at	Firm	Firm	Firm	Firm
Observations	43,485	43,485	38,971	27,244
R-squared	0.637	0.201	0.198	0.203
Number of clusters	5,123	5,123	5,123	5,123

Emerging Market Economies

	(1) Pool	(2) Panel	(3) Without 2008-2009	(4) Revenue increases
Electricity	8.120***	7.406**	8.300**	7.832**
	(1.743)	(3.175)	(3.449)	(3.740)
Roads	8.178***	2.287***	2.037***	1.902**
	(1.370)	(0.679)	(0.722)	(0.779)
Schools and Hospitals	7.764***	4.578**	4.777**	3.898**
	(2.376)	(1.788)	(2.171)	(1.663)
Water and Sanitation	12.28***	4.965*	5.587*	4.829
	(4.318)	(2.593)	(2.973)	(4.011)
Fixed effects	Country	Firm	Firm	Firm
Clustered at	Firm	Firm	Firm	Firm
Observations	4,095	4,095	3,660	2,539
R-squared	0.563	0.157	0.168	0.161
Number of clusters	556	556	556	556

Source: Author's estimations based on Compustat and Orbis.
Note: This table presents the results of regressions of employment on revenues in millions of 2015 US dollars. Model 1 assumes that labor moves freely across companies within sectors, while models 2–4 assume that labor is sticky. For robustness, Model 3 restricts the estimations to the years 1999–2007 and 2010–17, that is, without the global fiinancial crisis years of 2008–09, and Model 4 computes the impact on employment of revenue increases only. The sample data are for 1999–2017, and only firms with at least five annual observations were kept. Heteroskedasticity-robust standard errors clustered at the firm level are reported in parentheses; * denotes significance at 10 percent, ** significance at 5 percent, and *** significance at 1 percent.

Online Annex Table 2.4.4. Employment Intensity by Sectors and Income Group

Income group	Electricity	Roads	Schools and Hospitals	Water and Sanitation
Advanced economies	3.3	2.4	1.5	2.0
Emerging market economies	7.8	5.2	6.2	8.6
Low-income developing countries	12.3	8.0	10.9	15.2

Source: Author's estimations based on Compustat and Orbis.
Note: This table presents the results of regressions of employment on revenues in millions of 2015 US dollars. The coefficients for advanced aconomies and emerging market economies assume partial labor mobility across firms within sectors. The coefficients for low-income developing economies are computed as a linear extrapolation from advanced aconomies and emerging market economies. The sample data are for 1999–2017, and only firms with at least five annual observations were kept.

As a complementary analysis, the labor impact of public spending on research and development (R&D) is computed using a similar approach. Country-level data from the Organisation for Economic Co-operation and Development (OECD) on R&D disaggregated by recipient type are used, and the pass-through from R&D spending to employment is then computed. Overall, 587 observations are collected for 40 countries from 1999 to 2015 (with gaps). The blurry "intramural" R&D category is excluded. Annual shares of GDP spending are converted to constant 2015 US dollars, and panel regressions analogous to those for public investment are run. Annex Table 2.4.5 reports the results of the regressions regarding R&D spending by recipient type in OECD countries.

Government R&D generates an estimated 4.8 jobs per $1 million invested, while higher education R&D is nearly twice higher, possibly because it focuses on fundamental research and requires less capital than government R&D. Higher education, however, only accounts on average for 0.36 percent of GDP (or 20 percent of total R&D spending) and government for 0.22 percent of GDP (or about 13 percent of total R&D spending). The largest R&D spending was carried out by business for a total of 1.1 percent of GDP and 61 percent of total spending in R&D. Basic R&D is long-term and is primarily financed by the public sector, while the private sector mainly finances applied R&D, which is typically medium-term. The job content of green R&D is estimated at 3 to 8 jobs per $1 million of investment (IEA 2020); that is, at a similar cost than conventional R&D, green R&D can have a larger impact on job creation.

Online Annex Table 2.4.5. Employment Intensity in Research & Development by Recipient Type

	(1)	(2)	(3)	(4)
	Government	Higher Education	Business	Non-Profit
Spending in R&D (US$ million)	4.837***	10.99***	10.55**	4.477**
	(1.281)	(3.970)	(4.609)	(2.020)
Country fixed effects	Yes	Yes	Yes	Yes
Cluster at firm level	Yes	Yes	Yes	Yes
Observations	409	405	414	287
R-squared	0.690	0.425	0.635	0.331
Number of clusters	36	36	37	25

Source: Author's estimations based on Organisation for Economic Co-operation and Development (OECD) statistics.
Note: This table presents the results of panel regressions of employment on spending in R&D in millions of 2015 US dollars in OECD countries. The models correspond to recipients of R&D financing: government, higher education, business, and private non-profit organizations. The sample data are for 1999–2015. Heteroskedasticity-robust standard errors clustered at the country level are reported in parentheses; * denotes significance at 10 percent, ** significance at 5 percent, and *** significance at 1 percent.

Public investment policies should take into account local versus global and political economy constraints and tradeoffs. SOEs operate in virtually every country, most commonly in sectors such as public utilities, energy, transportation, and banking. According to International Labour Organization data, SOEs represent, on average, 3 percent of the labor force, compared to 13 percent of the labor force that works for the general government. In some countries, SOEs employ large parts of the workforce.

When investments are undertaken by SOEs, job intensity is found to be 30 percent higher (Baum and others 2019). Possible explanations for this finding are that SOEs tend to be large and subcontract fewer jobs and that SOEs have an implicit employment remit and low labor productivity. This result is especially important in emerging markets economies and low-income developing countries, where SOEs account for more than half of all infrastructure project commitments (IMF 2020) and often employ large parts of the workforce.

D. Discussion and Conclusions

The negotiations for another stimulus package are still ongoing in the *United States* as of this writing.[5] European leaders have agreed to create a €750 billion ($858 billion) recovery fund to rebuild European Union economies, on top of what country members are spending (Frater and Toh 2020). In the past quarter, governments around the globe have allocated trillions to the recovery.

An increase in public investment worth 1 percent of GDP could create around 7 million jobs directly in advanced and emerging economies. The number of 7 million jobs is obtained by applying: (i) a job

[5] This include the Health, Economic Assistance Liability Protection & Schools (HEALS) Act, the Coronavirus Aid, Relief, and Economic Security (CARES) Act, and the Health and Economic Recovery Omnibus Emergency Solutions (HEROES) Act.

content of 4.9 jobs per $1 million invested for advanced economies (unweighted average of 2.3 in construction, 7.5 for green investment, and 4.8 for R&D) to an increase in investment worth 1 percent of the GDP in advanced economies (around $500 billion in 2020) and; (ii) a job content of 14.7 for emerging markets (three times the estimate for advanced economies, as per the regression estimates for the construction sector) to 1 percent of the GDP of emerging markets (around $320 billion).

These numbers may underestimate job creation because of several factors that go beyond the scope of the data, including:

a. Firms with less than five observations are excluded. The analysis may miss the employment increase in cyclical companies that are formed during fiscal expansion and disappear in times of fiscal consolidation.
b. Construction companies often outsource part of their work. To the extent that subcontractors do not appear in the sample of firms in the datasets, revenues of the upstream contractors will be computed without the counterpart employment increase of the downstream contractors.
c. The effects in low-income developing countries of additional employment are linearly extrapolated from advanced economies and emerging market economies. This relationship may arguably be convex: that is, the impact on employment is likely to increase exponentially the lower the income per capita.
d. These estimates do not include the indirect labor impact and spillovers (including Keynesian multiplier effects, into other sectors of the economy) and do not distinguish between maintenance and new projects, or between skilled and unskilled labor (*ceteris paribus*, maintenance projects and projects with a stronger unskilled labor component would create more jobs than estimated here).

Online Annex 2.5. Public Investment Fiscal Multiplier and Macroeconomic Uncertainty[1]

This annex explains the methodology and results for the analysis of how public investment multipliers depend on the degree of macroeconomic uncertainty and the state of the economy. Three exercises are undertaken: first, to revisit the macroeconomic impact of public investment shocks on growth, private investment, and employment; second, to assess whether the effects vary with the level of uncertainty surrounding the economic outlook and analyze the transmission channel; and third, to investigate how the level of growth mediates the effect of uncertainty on public investment multipliers.

Public investment shocks are identified as forecast errors of public investment spending relative to GDP, following the identification approach pioneered by Auerbach and Gorodnichenko (2012, 2013a) and commonly used in the recent literature on fiscal multipliers (see the October 2014 *World Economic Report*; Miyamoto and others 2020). This approach aligns the information sets of the economic agents and the econometricians thus overcoming the fiscal foresight problem, and is robust to omitted variables and misspecification.[2, 3] The analyses also minimize the likelihood that the estimates capture the potentially endogenous response of fiscal policy to the state of the economy by using the same-year's IMF *World Economic Outlook* (WEO) October forecast errors, as it is less likely that public investment decisions are affected by the business cycle in the same quarter (Blanchard and Perotti 2002).[4] Moreover, the analyses focus on positive shocks, since the objective of this *Fiscal Monitor* chapter is to assess the effectiveness of a discretionary public investment push to kick-start the recovery and support medium- to long-term growth. Thus, the shock to investment is defined as follows:

$$FE_{i,t} = PI_{i,t} - PI_{i,t}^{E}, and\ FE_{i,t}^{+} = FE_{i,t}\ \ if\ FE_{i,t} > 0,$$

where $PI_{i,t}$ is actual public investment spending as a share of GDP of country *i* in year *t*, and $PI_{i,t}^{E}$ is the forecast of public investment spending. Forecasts are taken mainly from the October publications of the IMF *World Economic Outlook* for the same year.[5]

Macroeconomic uncertainty is measured by the standard deviation of GDP growth rate forecasts across professional forecasters as published by Consensus Economics, using for each year the spring vintage of the forecasts. Several measures have been proposed as proxies for uncertainty in the literature and can be divided between backward- and forward-looking indicators. Backward-looking measures, like those derived from statistical models, are inappropriate to quantify the near-term wake of the current shock, as it lacks close historical parallels. Existing forward-looking measures capture different dimensions of uncertainty and include stock market volatility (Bloom 2009), Google News-based indexes of economic uncertainty, and economic policy uncertainty indexes based on newspaper coverage frequency (Baker, Bloom, and Davis 2016), as well as the subjective uncertainty about future business growth and the

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[1] This annex was prepared by William Gbohoui of the Fiscal Affairs Department.

[2] The fiscal foresight problem refers to the situation where economic agents anticipate changes in fiscal spending in advance and alter their investment and consumption behavior before the changes materialize. In such cases, relying on the change in public investment could lead to inconsistent estimates of the effects of public investment as the econometrician is using a smaller set of information compared to economic agents. For further details on the fiscal foresight problem, see Forni and Gambetti (2010), Leeper, Richter, and Walker (2012), Leeper, Walker, and Yang (2013), and Ben Zeev and Pappa (2014).

[3] Jordà (2005) argues that the local projection method is robust to misspecification and omitted variables biases.

[4] The results are qualitatively similar when using spring forecast errors.

[5] Due to data limitations, forecasts from the Fall issue of Organisation for Economic Co-operation and Development Economic Outlook for advanced economies are used because there are no forecasts of public investment for these economies during 2004–08 in IMF *World Economic Outlook* publications. Miyamoto and others (2020) follow a similar approach. Data coverage is presented in Online Annex Table 2.5.1.

disagreement among professional forecasters about the future dynamic of economic variables (Bachmann and others 2013; Bachmann, Elstner, and Sims 2013; Altig and others 2020). This analysis opts for the latter measure for several reasons. First, by focusing on GDP forecasts, the most basic economic aggregate, the analysis is capturing the uncertainty surrounding the broader macroeconomic outlook rather than uncertainty on Wall Street reflected by stock market volatility indexes. Online Annex Figure 2.5.1 indicates that uncertainty in the United States peaked around April 2020 when job losses mounted.[6] Second, high levels of disagreement between professional forecasters for simple variables like GDP growth are reasonable proxies for economic uncertainty and changes in professional forecasts have been found to predict subsequent changes in expectations in the broader population (Carroll 2003).[7] Moreover, the Consensus Forecast dataset allows for broad country coverage.

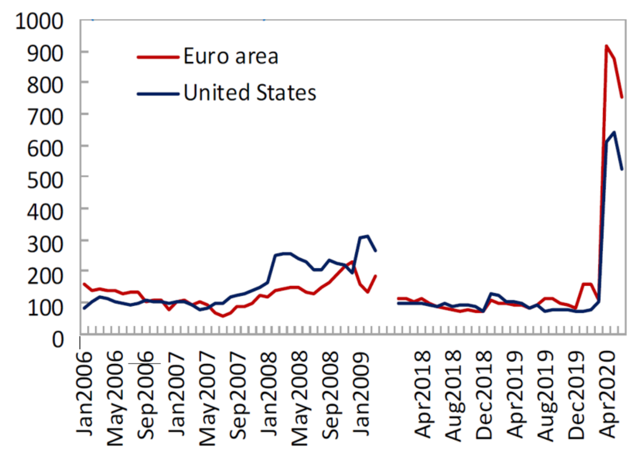
The primary sources of data used are the IMF *World Economic Outlook*, the Organisation for Economic Co-operation and Development (OECD), and Consensus Economics. The analysis covers 72 economies. The exact samples used vary with the exercises, depending on data availability. Online Annex Table 2.5.1 presents the economies included, time coverage, and the exercise where they appear.

The analysis starts by quantifying the macroeconomic effects of public investment on output, employment, and private investment using the following regression specification:

$$y_{i,t+k} - y_{i,t-1} = \alpha_i^k + \gamma_t^k + \beta_1^k FE_{i,t}^{+} + \theta^k M_{i,t} + \varepsilon_{i,t}^k, \qquad (1)$$

Online Annex Figure 2.5.1. Standard Deviations across GDP Forecasts

(January 2007 = 100)



Sources: Consensus Economics; and IMF staff calculations.

where y is the log of the macroeconomic variable of interest (real GDP, employment, and private investment), α is the country fixed effect, γ is the time fixed effect, FE is the identified public investment shock, and M is a set of control variables, including lagged GDP growth and lagged shocks. Equation (1) is estimated for each $k = 0, \ldots, 4$, where $k = 0$ is the year of the public investment shock. The impulse response functions of variables of interest are computed by using the estimated β^k. The confidence intervals associated with the impulse response functions are obtained by the estimated (clustered robust) standard errors of the coefficient β^k.

[6] Altig and others (2020) reach similar conclusions using alternative measures of broad economic uncertainty in the United States and the United Kingdom.

[7] Compared to news-based measures of uncertainty, professional forecasters' expectations are also likely to be better reflections of economic uncertainty than that expressed by journalists.

The baseline results (Online Annex Figure 2.5.2, Left-hand Panel) show that public investment shocks have statistically long-lasting effects on output. [8] An unanticipated 1 percentage point of GDP increase in public investment contemporaneously increases the level of output by about 0.23 percent (0.55 percent if the estimation is restricted to advanced economies, where public investment efficiency is typically higher). The literature on public investment multipliers is not conclusive regarding their size. The estimates in this analysis fall within the range, from around zero to as high as 2, reported by previous research (see April 2020 *World Economic Outlook* for a recent review of existing estimates).[9] The results also indicate that a discretionary public investment shock of 1 percentage point of GDP crowds in private investment by more than 3 percent over two years. However, exogenous public investment shocks are found to have no statistically significant effect on employment, except for having a positive short-term effect in advanced economies (Online Annex Table 2.5.4).

Online Annex Table 2.5.1. Sample of Countries Included in Analytical Exercises

Economies	Years	Excersises		
		Linear	Nonlinear	Nonlinear controlling for the state of the economy
Advanced Economies: Australia, Austria, Belgium, Canada, Czech Republic, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Portugal, Switzerland, United Kingdom, United States	1996-2019	X		
Emerging Markets and Low-Income Countries: Algeria, Angola, Antigua and Barbuda, Armenia, Bahrain, Bosnia and Herzegovina, Botswana, Brazil, Cabo Verde, Chile, China, Costa Rica, Croatia, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eswatini, Gabon, Guatemala, Iran, Jordan, Kosovo, Kuwait, Lebanon, Malaysia, Mauritius, Mexico, Mongolia, Montenegro, Morocco, Namibia, Oman, Pakistan, Panama, Peru, Romania, Saudi Arabia, Serbia, Seychelles, South Africa, Syria, Thailand, Turkey, United Arab Emirates, Uruguay, Venezuela, Afghanistan, Bangladesh, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Comoros, Republic of Congo, Côte d'Ivore, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, The Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Honduras, Kyrgyz Republic, Lesotho, Madagascar, Malawi, Mali, Moldova, Mozambique, Nicaragua, Niger, Nigeria, Rwanda, São Tome and Principe, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Yemen, Zambia.	1990-2019	X		
Advanced Economies: Australia, Austria, Belgium, Canada, Czech Republic, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Korea, Netherlands, New Zealand, Portugal, Switzerland, United Kingdom, United States	1996-2019		X	X
Emerging Markets: Armenia, Bosnia and Herzegovina, Brazil, Chile, China, Costa Rica, Croatia, Dominican Republic, Ecuador, El Salvador, Guatemala, Malaysia, Mexico, Pakistan, Panama, Peru, Romania, Serbia, Thailand, Turkey, Uruguay, Venezuela	1994-2019		X	X

Source: IMF staff calculations.

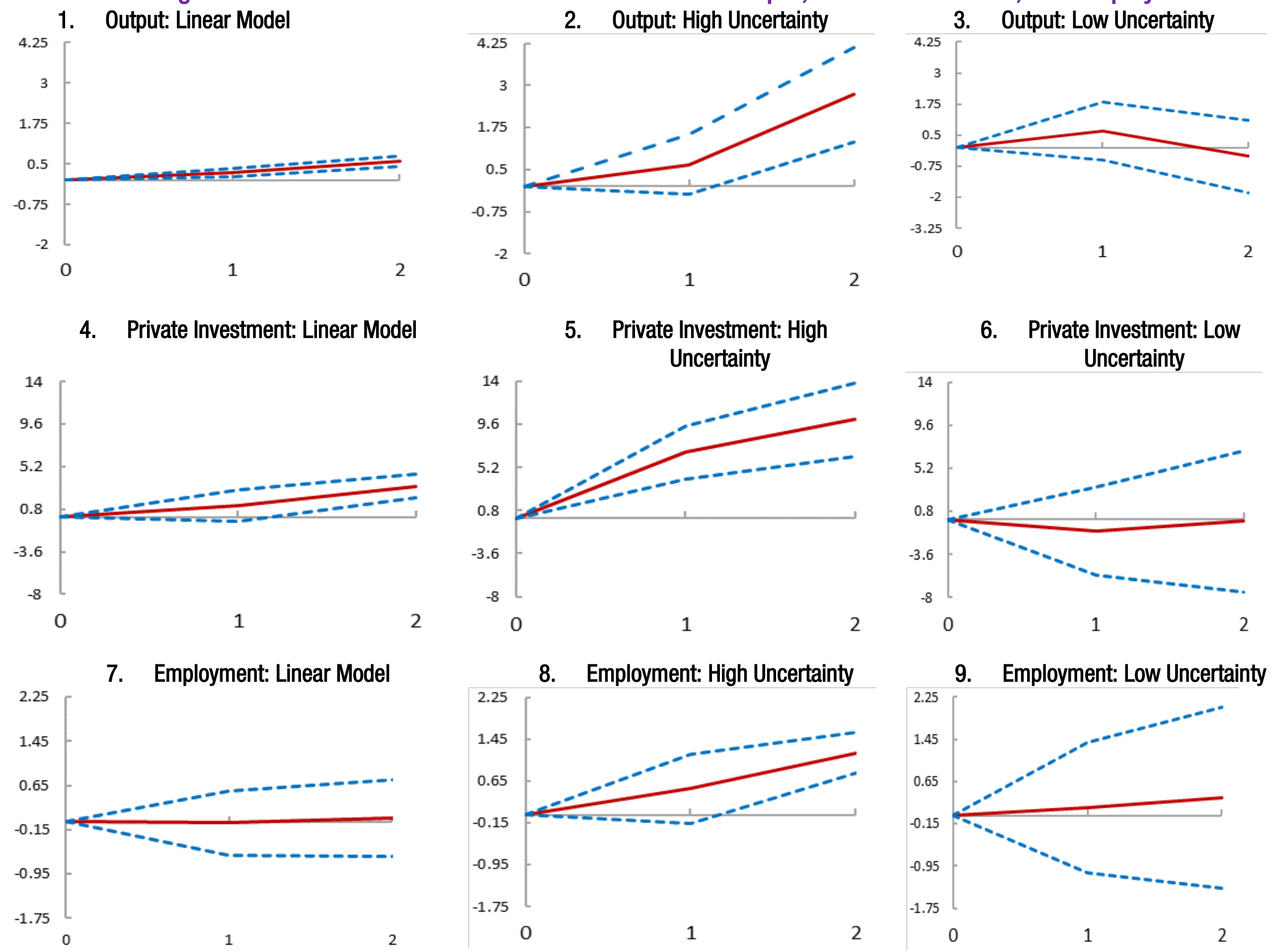
There are unique features of the COVID-19 crisis that should be considered when assessing the potential impact of a public investment push at the current juncture. For instance, fiscal multipliers tend to be larger in deeper recessions (Blanchard and Leigh 2013; Fatás and Summers 2018). But supply constraints resulting from the lockdown policies critical to enable social distancing could reduce fiscal multipliers in phase 2 of the recovery compared to phase 3, when lockdowns are lifted (Guerrieri and others 2020). On the other hand, the world is currently experiencing a radically new level of uncertainty as questions regarding the trajectory of the virus complicate the economic outlook. The literature suggests that uncertainty could have a negative effect on economic activity if firms postpone their hiring and investment decisions (Bernanke 1983; Bachmann, Elstner, and Sims 2013; Baker, Bloom, and Davis 2016). But little is known regarding how uncertainty could affect the transmission of fiscal policy shocks to the economy. Moreover, the findings from the few papers that have addressed the questions are not conclusive. High uncertainty could reduce the fiscal multiplier if private spending does not react to a

[8] Detailed results are presented in Online Annex Tables 2.5.2, 2.5.3 and 2.5.4.

[9] Differences in the size of the multipliers often reflect differences in sample size, identification, and estimation approaches, as well as in model specification. By controlling for the lags of both the public investment shock and the growth rate, on top of country and year fixed effects, the regression analysis has opted for a better prediction power for the model, suggesting that estimated multipliers should be considered as lower-bound estimates. A robustness check suggests that multipliers could be larger if fewer control variables are considered (results available upon request).

fiscal stimulus due to uncertainty and precautionary savings (Alloza 2018; Bloom and others 2018). Conversely, high uncertainty could increase the fiscal multiplier if the private sector perceives positive investment shocks as a government's commitment to promote economic growth and reacts strongly by increasing private spending (Bachmann and Sims 2012; Berg 2019).

Online Annex Figure 2.5.2. Effects of Public Investment Shocks on Output, Private Investment, and Employment.



Source: IMF staff calculations.
Note: t=1 is the year of the shock; dashed lines denote 90 percent confidence bands. Shock represents an exogenous 1 percentage point of GDP increase in public investment spending.

To make multiplier estimates more relevant for the current economic juncture, the analysis extends the literature on the state dependency of fiscal multipliers to the degree of macroeconomic uncertainty.[10] It assesses the sensitivity of public investment multipliers to the degree of macroeconomic uncertainty by estimating the following specification:

$$y_{i,t+k} - y_{i,t-1} = \alpha_i^k + \gamma_t^k + \beta_1^k G(z_{i,t}) FE_{i,t}^{+} + \beta_2^k \left(1 - G(z_{i,t})\right) FE_{i,t}^{+} + \theta^k M_{i,t} + \varepsilon_{i,t}^k$$

with

[10] The literature has established that multipliers depend on several conditions, including the stance of monetary policy, the point in the business cycle, the degree of openness, the source of financing, and the quality of governance and public investment management institutions (see Mineshima, Poplawski-Ribeiro, and Weber 2014; and Miyamoto and others 2020).

$$G(z_{i,t}) = \frac{\exp(-\delta z_{it})}{1+\exp(-\delta z_{it})},\ \delta > 0, \qquad (2)$$

where $G(\cdot)$ is the transition function between different levels of uncertainty in which z is the indicator of the degree of uncertainty normalized to have zero mean and unit variance. δ, the curvature of the transition function, is set to 1, following the literature (Miyamoto and others 2020).[11]

The results indicate that public investment has stronger effects on output, employment, and investment under high uncertainty (Online Annex Figure 2.5.2, Middle Panel).[12] The multiplier peaks at 2.7 over two years during the period of high uncertainty, versus 0.6 for the baseline estimate. Public investment multipliers prove statistically insignificant in periods of low uncertainty, suggesting that positive estimates for multipliers tend to be driven by periods of high uncertainty. These results extend to a panel of countries the findings by Bachman and Sims (2012) for the *United States* and by Berg (2019) for *Germany* that fiscal multipliers are higher than 2 in periods of high uncertainty. The crowding-in effects on private investment are also larger in periods of high uncertainty, suggesting that public investment shocks could raise growth in the medium-term as they increase the productive capacity of the economy. The results also indicate that unanticipated public investment shocks have significant and long-lasting effects on employment when economic uncertainty is high.

An increase of public investment of 1 percent of GDP globally could increase employment by 26 million in advanced and emerging economies. This job impact obtains from applying the point estimate of an increase of total employment by 1.2 percent over two years in response to an unexpected 1 percentage point of GDP increase in public investment to the 2019 October WEO total employment estimate of around 2.2 billion in advanced economies and emerging markets. Applying the lower and upper bounds of the 90 percent confidence interval of the estimate, a 1 percentage point of GDP shock to public investment could increase employment by 20 million to 33 million over a period of two years.[13]

These findings suggest that during periods of heightened uncertainty, increases in public investment might signal a government commitment to aggregate stability, leading to a stronger private demand as response. For instance, confidence of households and firms is considered a critical factor in the transmission of fiscal shocks into economic activity. Bachmann and Sims (2012) illustrated this effect by showing that public spending also has an indirect effect, where fiscal policy influences confidence that later influences output. In this annex, confidence is proxied by two indicators: the mean growth expectation and the standard deviation between forecasters. For instance, higher growth forecasts are reasonable indication of an increase in confidence of economic agents about future economic developments. But one could argue that an increase in the mean growth forecast can be driven by overoptimistic expectations by a very few forecasters. To overcome this well-known limit of the mean, the analysis also considers the standard deviation among forecasters. The rationale is that an increase in mean growth expectation combined with a reduction in the disagreement between forecasters about future growth development reflects an improvement in confidence about the future of the economy. To test the validity of the confidence channel in this annex, the analysis then assesses the effect of public investment shocks on the mean expectations and standard deviations of future growth by Consensus Economics forecasters using the specification below:

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[11] The results are robust to different values of δ (see the robustness section below).

[12] The results are robust to alternative measure of investment shocks, and to different specification and estimation methods (see the robustness section below). Detailed results are provided in Online Annex Table 2.5.5

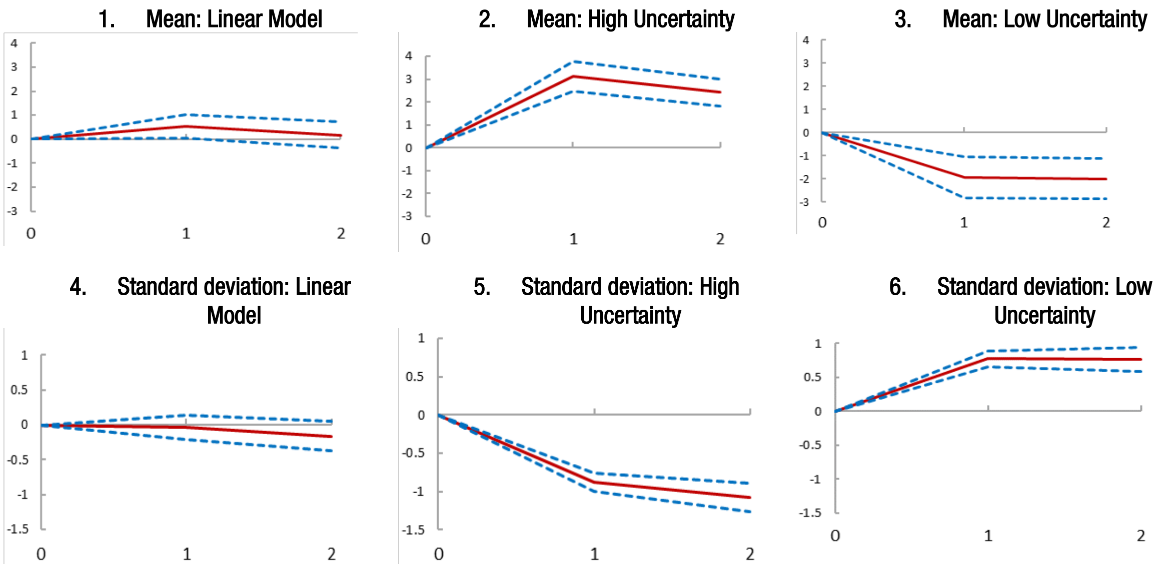
[13] Advanced and emerging economies constitute the right sample to which to apply the coefficients because the nonlinear regressions include only these two groups of countries, as shown by Online Annex Table 2.5.1.

$$X_{i,t+k} - X_{i,t} = \alpha_i^k + \gamma_t^k + \beta^k FE_{i,t}^+ + \theta^k M_{i,t} + \varepsilon_{i,t}^k, \qquad k = 1, \dots, 5, \qquad (3)$$

where X is the mean forecast of GDP (the standard deviation of GDP forecast) at the spring vintage of Consensus Economics, α is the country fixed effect, γ is the time fixed effect, and M includes lagged GDP growth and the lag of investment shocks.

Online Annex Figure 2.5.3. Effects of Public Investment Shocks on Mean and Standard Deviation of GDP Forecasts.

(Percentage point of GDP increase in public investment spending)



Source: IMF staff calculations.
Note: t=1 is the year of the shock; dashed lines denote 90 percent confidence bands. Shock represents an exogenous 1 percentage point of GDP increase in public investment spending.

The results show that public investment shocks significantly increase the mean expectations of forecasters in the short term, but the effects turn statistically insignificant in the medium term (Online Annex Figure 2.5.3, Left-hand Panel). Public investment shocks are also found to reduce uncertainty around forecasts of future growth. However, the effects are insignificant at all time horizons.[14]

To further investigate the transmission channel of the effects of public investment on economic activity, the analysis assesses whether public investment has a nonlinear effect on confidence, using the following specification:

$$X_{i,t+k} - X_{i,t} = \alpha_i^k + \gamma_t^k + \beta_1^k G(z_{i,t}) FE_{i,t}^+ + \beta_2^k \left(1 - G(z_{i,t})\right) FE_{i,t}^+ + \theta^k M_{i,t} + \varepsilon_{i,t}^k\,. \qquad (4)$$

The results indicate that public investment shocks have nonlinear effects on confidence, depending on the degree of ex-ante economic uncertainty (Online Annex Figure 2.5.3, Middle and Right-hand Panels). During periods of high uncertainty, public investment shocks increase the mean growth expectations of economic agents and reduce forecasters' uncertainty about short-and-medium-term growth paths. Moreover, both effects are statistically significant. The reverse is true during periods of low uncertainty when unanticipated shocks to public investment reduce forecasters' expectation about future growth and increase the disagreement between growth forecasters. These findings suggest that during heightened uncertainty, unexpected public investment shocks signal government commitments to growth and

[14] See detailed estimation results in Online Annex Table 2.5.6

stability, boosting the confidence of private agents about future economic developments. The negative effect on confidence during normal times likely reflects the volatility induced by unexpected shocks to public investments. For instance, even during normal times, some agents may be concerned that the economy could take a downturn in the near future. A government spending shock during normal times could then simply confirm these pessimistic views, leading to erosion of confidence.

Overall, these findings suggest that at the current juncture, a public investment push could contribute to kick-start the recovery and promote long-run growth. The findings are consistent with the intuition that in a period of high uncertainty, positive investment shocks from the government might signal a commitment to aggregate stability, thereby raising sentiment, stimulating demand, and leading to an economic expansion, as discussed in the literature (Barsky and Sims 2011, 2012; Bachmann and Sims 2012). The findings tend to support the rationale that the effects of public investment shocks can be decomposed into two components: a direct effect, because the investment spending shock itself has a contemporaneous effect on output, and an indirect effect through which public investment impacts confidence, which in turn affects economic activity. The stronger crowding-in effects on private investment obtained during periods of high uncertainty suggest that by raising confidence, a public investment push is also likely to foster investment from businesses that might otherwise become very cautious and postpone their hiring and investment decisions.

Robustness

Several robustness exercises are undertaken to assess the sensitivity of the results to different sample size, alternative definition of forecast errors, and different specifications. As periods of high uncertainty are likely to be characterized by low growth, the robustness exercise investigates whether the stronger multipliers obtained during periods of high uncertainty instead reflect the effects of economic slack. The exercise allows the effects of uncertainty on the public investment multiplier to vary with the state of the economy by estimating the regression specification:

$$y_{i,t+k} - y_{i,t-1} = \alpha_i^k + \gamma_t^k + \beta_1^k Dummy_{i,t} G(z_{i,t}) FE_{i,t}^+ + \beta_2^k Dummy_{i,t} \left(1 - G(z_{i,t})\right) FE_{i,t}^+ + \theta^k M_{i,t} + \varepsilon_{i,t}^k, \quad (5)$$

where $Dummy_{i,t}$ is a dummy variable indicating whether the economy is in a low- or high-growth state. Year *t* is defined as a period of low growth if the growth rate of GDP in year *t* is lower than the average growth rate of the past three years.

The results suggest that the larger multipliers obtained during periods of high uncertainty are not driven by the correlation between high uncertainty and low growth (Online Annex Table 2.5.8.). For instance, the results show that, on average, the effects of public investment are lower in periods of low growth compared to periods with high growth. However, when uncertainty is heightened, public investment shocks have positive and statistically significant effects on output, private investment, and employment during periods of low growth. Moreover, during periods of high uncertainty, the difference in the size of the multiplier between high and low growth states tends to be statistically insignificant. These findings suggest that the degree of uncertainty is what matters for the effects of public investment shocks.

The analysis next considers a different definition of public investment shocks. Online Annex Table 2.5.9 shows the results when public investment shocks are defined as the difference between the realized investment and the spring forecast vintage. The conclusions are similar to those discussed above. Public investment multipliers are larger and statistically significant during periods of high uncertainty compared to normal times.

The same conclusions are reached when limiting the analysis to the subsample of advanced economies (Online Annex Table 2.5.10). Likewise, the results are robust to the introduction of additional control variables. Online Annex Table 2.5.11 indicates that public investment shocks have larger effects on output, investment, and employment during periods of high uncertainty when controlling for the output gap. The models are also estimated by considering two sample periods: the period prior to the global financial crisis (before 2007) and the period starting in 2007. The same conclusions as discussed above are reached for the period starting in 2007 (Online Annex Table 2.5.12). But the multipliers turn statistically insignificant when the model is estimated for the period before 2007, likely due to insufficient variation in the sample (Online Annex Table 2.5.13). For instance, there are relatively few episodes of positive investment shocks during the period before 2007, compared to the period starting in 2007. Finally, the models are estimated using different values of the curvature of the transition function δ. The results are broadly similar.[15]

Although these findings suggest that the public investment multiplier could be larger than in normal times, the level and nature of uncertainty in this crisis makes it difficult to extrapolate from historical patterns. As shown by the robustness exercise, the results require that the sample include some variation in the positive investment shocks. Moreover, different measures of uncertainty capture different dimensions of uncertainty and could lead to different results. The analysis here focuses on a simple measure of uncertainty that is available for a large range of countries and captures a broader macroeconomic uncertainty.

[15] The detailed results are available upon request.

Online Annex Table 2.5.2. Linear Effects of a Public Investment Shock on Output

	Whole Sample					Advanced Economies					Emerging and Developping Economies				
Dependent Variable: Output	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
Public investment shock	0.2335***	0.5822***	0.5247***	0.3361	0.1527	0.5510**	0.7030	0.0737	-0.3718	-1.3818	0.2202*	0.5863***	0.5569**	0.3820	0.2364
	(0.0807)	(0.1007)	(0.1877)	(0.2252)	(0.2366)	(0.2336)	(0.7856)	(1.5017)	(2.0758)	(2.4699)	(0.1115)	(0.1109)	(0.2191)	(0.2580)	(0.2401)
Lag of public investment shock	0.5910*	0.4580	0.3495	0.4199	0.1397	0.3614	0.3193	0.3375	-0.1326	-0.1651	0.6083*	0.4695	0.3551	0.4489	0.1574
	(0.3101)	(0.2915)	(0.3140)	(0.4258)	(0.2139)	(0.3375)	(0.6033)	(0.8758)	(1.3381)	(1.5874)	(0.3571)	(0.3346)	(0.3556)	(0.4885)	(0.2304)
Lag of real GDP growth rate	-0.0028	-0.0021	-0.0017	-0.0022*	-0.0020	0.0011	0.0015	0.0024	0.0008	0.0008	-0.0036	-0.0027	-0.0024**	-0.0027**	-0.0024**
	(0.0024)	(0.0018)	(0.0011)	(0.0011)	(0.0013)	(0.0016)	(0.0027)	(0.0037)	(0.0047)	(0.0060)	(0.0027)	(0.0020)	(0.0009)	(0.0010)	(0.0011)
Constant	-0.0579*	-0.0763**	-0.0532	-0.0345	0.0194	0.0269***	0.0605***	0.1024***	0.1573***	0.1864***	-0.0565	-0.0683	-0.0361	-0.0097	0.0590
	(0.0298)	(0.0382)	(0.0485)	(0.0607)	(0.0415)	(0.0052)	(0.0124)	(0.0193)	(0.0287)	(0.0374)	(0.0357)	(0.0462)	(0.0586)	(0.0732)	(0.0421)
Observations	389	389	389	389	389	213	213	213	213	213	176	176	176	176	176
R-squared	0.5533	0.7220	0.7387	0.7529	0.7976	0.7325	0.7249	0.7135	0.6967	0.7033	0.4883	0.7205	0.7533	0.7801	0.8540

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.3. Linear Effects of Public Investment Shocks on Private Investment

Depdent Variable: Private Investment	Whole Sample					Advanced Economies					Emerging and Developping Economies				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
Public investment shock	1.1611	3.2018***	3.6812***	3.2451***	1.8529*	3.5494	5.9359	3.4360	-1.9926	-3.9894	1.0748	3.1126***	3.7240***	3.5220***	2.1063*
	(1.0091)	(0.7399)	(0.7911)	(0.9979)	(1.0370)	(2.7993)	(4.0480)	(5.2732)	(4.8450)	(6.5015)	(1.1647)	(0.7918)	(0.8235)	(1.0308)	(1.1088)
Lag of public investment shock	1.9166**	1.5879*	1.0084	-0.2582	0.2205	1.0410	0.6190	-0.9432	0.3619	0.6359	1.9480**	1.6031	1.0701	-0.3054	0.1663
	(0.7635)	(0.9430)	(1.0700)	(1.1499)	(1.1428)	(0.9725)	(1.9764)	(3.8535)	(3.2858)	(4.1258)	(0.9314)	(1.1380)	(1.2794)	(1.3569)	(1.3189)
Lag of real GDP growth rate	0.0075	0.0023	0.0014	-0.0001	0.0021	0.0048	-0.0074	-0.0123	-0.0138	-0.0139	0.0081	0.0042	0.0042	0.0029	0.0055
	(0.0099)	(0.0051)	(0.0051)	(0.0057)	(0.0049)	(0.0038)	(0.0101)	(0.0172)	(0.0213)	(0.0225)	(0.0131)	(0.0068)	(0.0059)	(0.0065)	(0.0047)
Constant	1.8739***	1.6635***	1.5403***	1.9211***	1.9359**	0.0053	0.0883*	0.1773**	0.2878**	0.2981**	.8874**	1.6918***	1.5810***	2.0033***	2.0350***
	(0.0665)	(0.1284)	(0.1710)	(0.2050)	(0.2065)	(0.0199)	(0.0507)	(0.0790)	(0.1167)	(0.1230)	(0.0827)	(0.1569)	(0.1999)	(0.2301)	(0.2331)
Observations	386	386	386	386	386	213	213	213	213	213	173	173	173	173	173
R-squared	0.6480	0.6437	0.6349	0.6622	0.6940	0.4999	0.5109	0.4955	0.4872	0.5185	0.6667	0.6761	0.6834	0.7223	0.7515

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*$p < .10$; **$p < .05$; ***$p < .01$.

Online Annex Table 2.5.4. Linear of Effects of Public Investment Shocks on Employment

	Whole sample					Advanced Economies					Emerging and Developping Economies				
Dependent Variable: Employment	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
Public investment shock	-0.0248	0.0587	0.5528	0.4695	0.1928	0.5302*	0.8508	0.8189	0.2115	-0.3359	-0.3546	-0.3046	0.5207	0.8007	0.7449
	(0.3533)	(0.4175)	(0.4610)	(0.6862)	(0.8156)	(0.2743)	(0.6338)	(0.9696)	(1.4180)	(1.8337)	(0.5849)	(0.6471)	(0.7797)	(0.9975)	(0.8364)
Lag of public investment shock	0.3050	0.7170*	0.6047	0.5077	0.4216	0.3576	0.7259	0.5421	0.4316	0.0553	0.1284	0.5465	0.6153	0.6355	0.7720
	(0.3318)	(0.4252)	(0.4348)	(0.5834)	(0.7567)	(0.2633)	(0.4831)	(0.7746)	(1.0693)	(1.3132)	(0.4232)	(0.5929)	(0.6712)	(0.6206)	(0.7034)
Lag of real GDP growth rate	0.0042***	0.0045***	0.0044***	0.0042*	0.0043*	0.0032***	0.0044**	0.0054*	0.0047	0.0046	0.0049**	0.0041	0.0032	0.0042	0.0047
	(0.0014)	(0.0015)	(0.0016)	(0.0022)	(0.0025)	(0.0011)	(0.0020)	(0.0029)	(0.0038)	(0.0044)	(0.0024)	(0.0026)	(0.0027)	(0.0027)	(0.0028)
Constant	-0.0485*	-0.1048**	-0.1002	-0.0807	-0.0666	-0.0067	-0.0018	0.0132	0.0396	0.0579*	-0.0141	-0.0681	-0.0966	-0.1045	-0.1159
	(0.0270)	(0.0438)	(0.0612)	(0.0884)	(0.1183)	(0.0057)	(0.0093)	(0.0153)	(0.0238)	(0.0310)	(0.0411)	(0.0753)	(0.1184)	(0.1208)	(0.1259)
Observations	311	311	310	309	309	213	213	213	213	213	98	98	97	96	96
R-squared	0.5329	0.5800	0.6426	0.6425	0.6681	0.6347	0.6203	0.5810	0.5529	0.5771	0.4680	0.5189	0.6997	0.7423	0.7552

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.5. Effects of Macroeconomic Uncertainty on Investment Multipliers

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty*Investment shock	0.6501	2.7184***	2.4194***	1.9462*	2.1656	6.7531***	10.0691***	7.8311**	5.9543	7.6702	0.5088	1.1909***	1.9721***	2.1337***	2.6204***
	(0.5327)	(0.8446)	(0.7114)	(1.0370)	(1.3957)	(1.6337)	(2.3095)	(3.2494)	(4.3325)	(5.7214)	(0.4030)	(0.2337)	(0.3291)	(0.6631)	(0.7517)
Low uncertainty*Investment shock	0.6688	-0.3493	0.0107	0.5640	-0.4243	-1.1808	-0.2179	-0.1470	2.2647	-1.4287	0.1610	0.3435	0.6719	1.0405	0.7053
	(0.7122)	(0.8879)	(1.0875)	(1.3112)	(1.1356)	(2.7556)	(4.3849)	(5.6892)	(6.3950)	(7.1109)	(0.7536)	(1.0436)	(1.2971)	(1.4047)	(1.4638)
Lag of public investment shock	0.9027***	1.2937**	1.4290**	1.2130*	1.2494**	2.5867**	4.7986**	5.4293**	3.4732	2.6573	0.7718**	1.7119***	1.9132***	1.9539***	1.5140**
	(0.3139)	(0.5750)	(0.6213)	(0.6861)	(0.4543)	(0.9630)	(1.9927)	(2.2412)	(2.1796)	(1.9659)	(0.2832)	(0.4373)	(0.4944)	(0.5773)	(0.5610)
Lag of real GDP growth rate	-0.0002	-0.0005	-0.0008	-0.0031***	-0.0036**	0.0051	0.0018	-0.0019	-0.0080*	-0.0148*	0.0029***	0.0033**	0.0033**	0.0021*	0.0011
	(0.0009)	(0.0009)	(0.0010)	(0.0008)	(0.0015)	(0.0030)	(0.0025)	(0.0044)	(0.0046)	(0.0078)	(0.0010)	(0.0012)	(0.0012)	(0.0011)	(0.0014)
Constant	0.0058	0.0223***	0.0393***	0.0620***	0.0832***	-0.0647***	-0.0762**	-0.0477	-0.0183	0.0300	0.0020	0.0019	0.0040	0.0094	0.0204*
	(0.0040)	(0.0054)	(0.0061)	(0.0059)	(0.0064)	(0.0224)	(0.0299)	(0.0359)	(0.0387)	(0.0475)	(0.0023)	(0.0042)	(0.0057)	(0.0074)	(0.0101)
Observations	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147
R-squared	0.8234	0.8369	0.8520	0.8708	0.8920	0.7332	0.7390	0.7385	0.7336	0.7227	0.7335	0.7778	0.7825	0.7865	0.8008

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.6. Linear Effects of Public Investment Shocks on Mean and Standard Deviation of GDP Forecasts

Dependent Variable:	Mean Forecast of GDP					Standard Deviation of GDP Forecast				
	k=1	k=2	k=3	k=4	k=5	k=1	k=2	k=3	k=4	k=5
Public investment shock	0.5417*	0.1756	0.6620	-0.2058	0.1534	-0.0362	-0.1590	-0.0388	-0.0565	-0.1309
	(0.2929)	(0.3389)	(0.4670)	(0.4351)	(0.5085)	(0.1077)	(0.1322)	(0.1196)	(0.1333)	(0.1597)
Lag of public investment shock	-0.1682	0.1506	-0.3519*	-0.2419	-0.3450	-0.0820*	-0.0775	-0.0339	-0.0812	-0.0043
	(0.2212)	(0.2079)	(0.1884)	(0.3185)	(0.2103)	(0.0444)	(0.0647)	(0.0370)	(0.0517)	(0.0429)
Lag of real GDP growth rate	-0.0030***	-0.0018*	-0.0037***	-0.0031***	-0.0034***	0.0002*	0.0003***	0.0002**	0.0002***	0.0002*
	(0.0004)	(0.0009)	(0.0009)	(0.0010)	(0.0011)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Constant	-0.0550***	-0.0538***	-0.0459***	-0.0383***	0.0482***	0.0197***	0.0198***	0.0196***	0.0174***	-0.0027**
	(0.0045)	(0.0056)	(0.0057)	(0.0060)	(0.0068)	(0.0048)	(0.0041)	(0.0026)	(0.0033)	(0.0012)
Observations	147	137	133	128	124	144	134	130	125	121
R-squared	0.9036	0.8556	0.8539	0.8153	0.8484	0.8779	0.7518	0.8619	0.7970	0.7752

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
$^*p < .10$; $^{**}p < .05$; $^{***}p < .01$.

Online Annex Table 2.5.7. Nonlinear Effects of Public Investment Shocks on Mean and Standard Deviation of GDP Forecasts

Dependent Variable	Mean Forecast of GDP					Standard Deviation of GDP Forecast				
	k=1	k=2	k=3	k=4	k=5	k=1	k=2	k=3	k=4	k=5
High uncertainty # investment shock	3.1377***	2.4207***	2.1909***	2.4051***	1.7413**	-0.8800***	-1.0797***	-0.8850***	-1.0252***	-1.0542***
	(0.3969)	(0.3652)	(0.5280)	(0.2765)	(0.5936)	(0.0738)	(0.1143)	(0.0756)	(0.1640)	(0.0592)
Low uncertainty # investment shock	-1.9205***	-1.9936***	-1.2212*	-2.7303***	-1.3407*	0.7755***	0.7634***	0.7687***	0.9005***	0.7490***
	(0.5451)	(0.5308)	(0.6588)	(0.5642)	(0.6458)	(0.0702)	(0.1119)	(0.1322)	(0.1159)	(0.0956)
Lag of public investment shock	-0.2207	0.0848	-0.4108*	-0.3106	-0.3715	-0.0768***	-0.0636	-0.0370	-0.0598	0.0189
	(0.3084)	(0.2374)	(0.2187)	(0.3040)	(0.2441)	(0.0219)	(0.0629)	(0.0247)	(0.0611)	(0.0209)
Lag of real GDP growth rate	-0.0027***	-0.0015	-0.0033***	-0.0027**	-0.0032**	0.0000	0.0001*	0.0001	0.0001	0.0001
	(0.0004)	(0.0009)	(0.0008)	(0.0009)	(0.0011)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Constant	-0.0536***	-0.0511***	-0.0437***	-0.0344***	0.0453***	0.0193***	0.0187***	0.0187***	0.0159***	-0.0013
	(0.0042)	(0.0079)	(0.0067)	(0.0065)	(0.0065)	(0.0047)	(0.0039)	(0.0025)	(0.0028)	(0.0008)
Observations	145	135	131	126	122	144	134	130	125	121
R-squared	0.9171	0.8693	0.8625	0.8357	0.8540	0.9146	0.8272	0.9203	0.8722	0.8724

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
$^*p < .10$; $^{**}p < .05$; $^{***}p < .01$.

Online Annex Table 2.5.8. Effects of Macroeconomic Uncertainty: Interaction with the State of the Economy

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
Low growth # high uncertainty	0.2488	2.1653***	1.7494***	1.3708	1.6908	5.4141***	7.9872***	5.8203**	4.5905	5.9971	0.4255	0.9393*	1.7212***	1.9740***	2.4480***
	(0.6925)	(0.5981)	(0.5946)	(0.9029)	(1.2119)	(1.4678)	(1.9777)	(2.1463)	(3.7727)	(5.2847)	(0.5537)	(0.4708)	(0.4668)	(0.5813)	(0.5626)
High growth # high uncertainty	2.9538	4.1963	4.1621	5.7293	7.2854	7.8608	11.5245	5.7331	9.3518	27.3928*	-1.9197	-1.6648	-2.7817	-4.5703	-2.2644
	(1.7712)	(2.6947)	(5.4728)	(5.9405)	(4.8537)	(8.3212)	(11.6058)	(13.3406)	(17.1064)	(13.3163)	(1.6784)	(2.7816)	(4.2932)	(4.7957)	(4.8120)
Low growth # low uncertainty	0.9289	-0.1436	-0.0620	1.1123	1.1161	-1.4056	-4.0854	-3.6491	1.6646	-0.9575	0.6002	0.9417	1.4310	1.5015	1.3360
	(1.3391)	(1.3995)	(1.4733)	(1.8224)	(1.7965)	(3.2983)	(4.1567)	(3.5499)	(5.2117)	(4.5718)	(0.8587)	(1.1785)	(1.3699)	(1.5042)	(1.4970)
High growth # low uncertainty	-1.6921	-2.7405	-2.7505	-4.5968	-7.0339*	-2.0616	-1.9904	-2.1794	-6.2059	-22.9138*	2.3073	2.3898	3.5505	4.6630	2.7674
	(1.4745)	(2.2364)	(3.9506)	(4.3855)	(3.5456)	(6.6601)	(9.3879)	(9.7653)	(12.4384)	(11.1738)	(1.4093)	(2.2137)	(2.9894)	(3.2537)	(2.9934)
Low (versus high) growth period	-0.0177***	-0.0307***	-0.0348***	-0.0435***	-0.0485***	-0.0352	-0.0508	-0.0907**	-0.1072	-0.1134	-0.0020	-0.0128*	-0.0227***	-0.0302***	-0.0319**
	(0.0061)	(0.0078)	(0.0098)	(0.0144)	(0.0171)	(0.0214)	(0.0350)	(0.0432)	(0.0642)	(0.0678)	(0.0047)	(0.0065)	(0.0077)	(0.0102)	(0.0128)
Lag of public investment shock	0.6916***	1.0549**	1.1529*	1.0173	1.0798*	1.8065	3.8722*	4.7845**	3.1942*	2.1217	0.6754***	1.5426***	1.7918***	1.9758***	1.5263***
	(0.2005)	(0.4351)	(0.5545)	(0.6656)	(0.5801)	(1.2609)	(2.0138)	(2.0055)	(1.5825)	(2.3703)	(0.2241)	(0.3540)	(0.3609)	(0.3407)	(0.3660)
Constant	0.0232***	0.0522***	0.0738***	0.0976***	0.1192***	-0.0135	-0.0041	0.0523	0.0733	0.1121*	0.0091**	0.0205***	0.0313***	0.0413***	0.0514***
	(0.0029)	(0.0046)	(0.0067)	(0.0082)	(0.0104)	(0.0121)	(0.0218)	(0.0395)	(0.0496)	(0.0549)	(0.0043)	(0.0064)	(0.0079)	(0.0099)	(0.0124)
Observations	147	147	147	147	147	147	147	147	147	147	147	147	147	147	147
R-squared	0.8793	0.8988	0.9042	0.9045	0.9142	0.7750	0.8085	0.8201	0.7816	0.7513	0.6612	0.7763	0.8082	0.8343	0.8377

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
$^*p < .10$; $^{**}p < .05$; $^{***}p < .01$.

Online Annex Table 2.5.9. Effects of Macroeconomic Uncertainty on Investment Multipliers: Alternative Definition of Investment Shocks

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty	0.0996	2.0931**	1.4860	0.4329	0.7706	6.7248***	10.6270**	8.4824*	4.1360	6.6487	0.1793	0.9010**	1.3265*	1.3419	1.7039
	(0.5948)	(0.9029)	(0.9096)	(0.9559)	(1.3616)	(2.2162)	(4.3037)	(4.5695)	(4.4289)	(5.8086)	(0.4101)	(0.3414)	(0.7564)	(1.1844)	(1.2905)
Low uncertainty	0.7258	-0.4226	0.2398	0.7143	0.3948	-4.2983*	-3.8949	-4.8553	-3.1858	-5.9449	0.3703	0.7763	0.8880	0.8543	0.3229
	(0.9557)	(0.8810)	(0.9528)	(1.3565)	(1.1168)	(2.0851)	(3.2398)	(4.6699)	(4.7154)	(5.0304)	(0.5957)	(0.6637)	(1.1628)	(1.3648)	(1.4419)
Lag of public investment shock	0.5472	0.7633	0.4238	0.5489	0.5605	1.9618**	1.5728	1.6266	0.5745	0.2301	0.6641**	1.1124***	1.2255**	1.1767*	0.9146
	(0.3939)	(0.4897)	(0.5507)	(0.5853)	(0.3784)	(0.7818)	(1.3914)	(1.4719)	(1.7617)	(1.4046)	(0.2500)	(0.3761)	(0.4775)	(0.5869)	(0.5704)
Lag of real GDP growth rate	-0.0004	-0.0005	-0.0009	-0.0029***	-0.0039***	0.0063**	0.0027	0.0006	-0.0059	-0.0130**	0.0028***	0.0031**	0.0030**	0.0017	0.0007
	(0.0007)	(0.0009)	(0.0009)	(0.0007)	(0.0010)	(0.0028)	(0.0030)	(0.0032)	(0.0041)	(0.0053)	(0.0008)	(0.0011)	(0.0012)	(0.0013)	(0.0017)
Constant	0.0176***	0.0376***	0.0588***	0.0824***	0.1030***	-0.0320*	-0.0126	0.0137	0.0479	0.0852	0.0021	0.0076*	0.0138**	0.0231**	0.0329***
	(0.0039)	(0.0051)	(0.0071)	(0.0086)	(0.0099)	(0.0174)	(0.0287)	(0.0353)	(0.0448)	(0.0503)	(0.0025)	(0.0040)	(0.0061)	(0.0086)	(0.0107)
Observations	145	145	145	145	145	145	145	145	145	145	145	145	145	145	145
R-squared	0.7978	0.8524	0.8719	0.8896	0.9162	0.6827	0.7120	0.6918	0.6776	0.6966	0.7721	0.8063	0.7961	0.7984	0.8077

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.10. Effects of Macroeconomic Uncertainty on Investment Multipliers: Sample Restricted to Advanced Economies

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty	0.6175	2.6436***	2.3137***	1.9147*	2.0275	6.6584***	10.0391***	7.6912**	5.9012	7.3596	0.5262	1.1051***	1.9079***	2.0983**	2.5210***
	(0.5132)	(0.7624)	(0.6437)	(0.9810)	(1.2938)	(1.5433)	(2.2570)	(3.1729)	(4.2241)	(5.4983)	(0.3902)	(0.1939)	(0.3293)	(0.6672)	(0.7805)
Low uncertainty	0.6835	-0.2699	-0.0404	0.7296	-0.2988	-1.3671	-0.0713	-0.1978	2.6691	-0.6278	0.2982	0.3872	0.7021	1.1720	0.9242
	(0.6967)	(0.8484)	(1.0735)	(1.2336)	(1.0556)	(2.7628)	(4.2462)	(5.5819)	(6.1155)	(6.7439)	(0.6787)	(1.0386)	(1.2926)	(1.3551)	(1.3984)
Lag of public investment shock	0.8936**	1.2531*	1.4425**	1.1386	1.1836**	2.6596**	4.7326**	5.4397**	3.2936	2.2845	0.7137**	1.6859***	1.8948***	1.8940***	1.4109**
	(0.3151)	(0.5822)	(0.6328)	(0.6747)	(0.4754)	(0.9172)	(1.9595)	(2.1596)	(2.1670)	(1.8435)	(0.2612)	(0.4552)	(0.5036)	(0.5774)	(0.5720)
Lag of real GDP growth rate	-0.0001	-0.0002	-0.0003	-0.0030***	-0.0031**	0.0056	0.0018	-0.0013	-0.0080	-0.0140	0.0027**	0.0036**	0.0036**	0.0021	0.0014
	(0.0010)	(0.0010)	(0.0008)	(0.0008)	(0.0013)	(0.0032)	(0.0027)	(0.0044)	(0.0048)	(0.0078)	(0.0010)	(0.0014)	(0.0014)	(0.0012)	(0.0013)
Constant	0.0232***	0.0496***	0.0874***	0.1368***	0.1622***	0.0020	0.0153	0.0805	0.1675**	0.2012***	-0.0047	-0.0058	0.0020	0.0222	0.0393*
	(0.0048)	(0.0101)	(0.0162)	(0.0196)	(0.0200)	(0.0347)	(0.0605)	(0.0651)	(0.0608)	(0.0622)	(0.0067)	(0.0116)	(0.0143)	(0.0173)	(0.0186)
Observations	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
R-squared	0.7991	0.8185	0.8318	0.8512	0.8755	0.7056	0.7104	0.6997	0.7009	0.7017	0.6922	0.7297	0.7258	0.7289	0.7556

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.11. Effects of Macroeconomic Uncertainty on Investment Multipliers, Controlling for the Output Gap

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty	0.5782	2.7451***	2.5258***	2.0884**	2.3636**	6.6050***	10.1326***	8.1470***	6.4041*	8.2693*	0.4635	1.1459***	1.9730***	2.1994***	2.7499***
	(0.5275)	(0.8229)	(0.6191)	(0.8711)	(1.1186)	(1.8128)	(2.2996)	(2.7099)	(3.5424)	(4.5734)	(0.4049)	(0.2479)	(0.3362)	(0.7227)	(0.8481)
Low uncertainty	0.5958	-0.3222	0.1186	0.7083	-0.2234	-1.3311	-0.1535	0.1734	2.7211	-0.8209	0.1150	0.2979	0.6729	1.1073	0.8367
	(0.7413)	(0.8504)	(0.9990)	(1.1841)	(0.8944)	(2.8380)	(4.3264)	(5.3792)	(5.7270)	(6.3859)	(0.7138)	(1.0145)	(1.2810)	(1.4451)	(1.5631)
Lag of public investment shock	0.7172*	1.3626**	1.7032***	1.5795**	1.7596***	2.2048**	4.9624**	6.2434***	4.6327**	4.2016**	0.6548**	1.5960***	1.9155***	2.1234***	1.8478***
	(0.3494)	(0.5753)	(0.5892)	(0.6160)	(0.3748)	(0.9034)	(2.0234)	(2.1389)	(1.9655)	(1.6837)	(0.2863)	(0.4425)	(0.4878)	(0.5308)	(0.5049)
Lag of real GDP growth rate	-0.0015**	0.0000	0.0011	-0.0006	-0.0001	0.0025	0.0029	0.0036	-0.0001	-0.0043	0.0021**	0.0025**	0.0033**	0.0032*	0.0033**
	(0.0007)	(0.0012)	(0.0014)	(0.0015)	(0.0014)	(0.0024)	(0.0034)	(0.0049)	(0.0033)	(0.0040)	(0.0007)	(0.0009)	(0.0014)	(0.0017)	(0.0015)
WEO: Output gap in percent	0.0040***	-0.0015	-0.0059***	-0.0078***	-0.0109***	0.0082**	-0.0035	-0.0174*	-0.0248**	-0.0330**	0.0025**	0.0025	-0.0000	-0.0036**	-0.0071***
	(0.0009)	(0.0014)	(0.0019)	(0.0025)	(0.0027)	(0.0038)	(0.0062)	(0.0089)	(0.0116)	(0.0124)	(0.0010)	(0.0017)	(0.0018)	(0.0017)	(0.0018)
Constant	0.0121***	0.0196***	0.0293***	0.0485***	0.0645***	-0.0519**	-0.0829**	-0.0774**	-0.0607*	-0.0262	0.0062***	0.0061	0.0040	0.0034	0.0086
	(0.0036)	(0.0061)	(0.0075)	(0.0073)	(0.0087)	(0.0192)	(0.0301)	(0.0368)	(0.0349)	(0.0474)	(0.0017)	(0.0040)	(0.0052)	(0.0064)	(0.0083)
Observations	146	146	146	146	146	146	146	146	146	146	146	146	146	146	146
R-squared	0.8445	0.8375	0.8614	0.8823	0.9093	0.7427	0.7388	0.7497	0.7545	0.7569	0.7568	0.7851	0.7825	0.7925	0.8188

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.12. Effects of Macroeconomic Uncertainty on Investment Multipliers, Post Global Financial Crisis

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty	0.7806	3.6642**	3.1745**	2.5939	3.4642	6.0464**	7.1319*	3.7738	1.8833	4.2306	0.6458	1.6240***	2.2965***	2.2599**	2.6808**
	(0.9044)	(1.4766)	(1.2706)	(1.8481)	(2.2440)	(2.5585)	(3.5774)	(5.5044)	(7.5180)	(8.9424)	(0.5117)	(0.5213)	(0.7186)	(0.9927)	(1.1699)
Low uncertainty	-0.6512	-2.5890	-2.0240	-1.5408	-1.8122	-2.9444	-6.1944	-2.8957	-4.2240	-7.3643	-0.6483	-1.1904	-0.9707	-0.7101	-1.6887
	(2.0303)	(2.5572)	(3.8420)	(4.4846)	(4.9512)	(4.8340)	(8.2691)	(15.6194)	(15.9270)	(17.6361)	(1.2628)	(2.0490)	(2.8971)	(3.6518)	(4.1250)
Lag of public investment shock	1.3779	1.0233	1.0969	1.4900	0.5658	4.1401	13.3992**	14.9136	12.1167	15.5403	1.2436	1.6336*	2.1126	2.1821	2.0188
	(1.6729)	(1.6905)	(2.9047)	(4.2673)	(4.6706)	(4.5953)	(5.6072)	(9.2434)	(12.5846)	(13.1126)	(0.7505)	(0.9075)	(1.6063)	(1.9134)	(2.7765)
Lag of real GDP growth rate	0.0005	0.0005	-0.0009	0.0010	-0.0039	0.0036	0.0102	0.0041	0.0033	-0.0116	0.0043***	0.0021	0.0037	0.0057	0.0027
	(0.0031)	(0.0041)	(0.0057)	(0.0052)	(0.0057)	(0.0061)	(0.0103)	(0.0154)	(0.0167)	(0.0174)	(0.0006)	(0.0027)	(0.0038)	(0.0058)	(0.0069)
Constant	0.0168	0.0401	0.0220	0.0412	0.0942	-0.0080	-0.1346	-0.2579	-0.1944	-0.0918	-0.0120	0.0042	-0.0192	-0.0279	0.0020
	(0.0284)	(0.0323)	(0.0515)	(0.0781)	(0.0871)	(0.0673)	(0.0933)	(0.1830)	(0.2487)	(0.2685)	(0.0139)	(0.0191)	(0.0320)	(0.0453)	(0.0575)
Observations	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
R-squared	0.9111	0.9271	0.9200	0.9177	0.9227	0.8864	0.9055	0.8619	0.7725	0.7050	0.9291	0.9403	0.9395	0.9099	0.8834

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex Table 2.5.13. Effects of Macroeconomic Uncertainty on Investment Multipliers Prior to the Global Financial Crisis

Dependent Variable	Output					Private Investment					Employment				
	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4	k=0	k=1	k=2	k=3	k=4
High uncertainty	0.2538	-2.7124	-0.0248	1.3728	1.4747	-1.1267	-0.5447	6.2409	14.0427	20.9489	-2.1374	-3.3096	-2.0691	-1.5694	-0.5724
	(1.8258)	(3.6969)	(5.6808)	(4.7346)	(5.0849)	(5.5216)	(12.5603)	(23.4415)	(29.1602)	(21.6816)	(1.9956)	(2.4147)	(3.8119)	(3.9155)	(5.0622)
Low uncertainty	2.4541	5.7021*	3.8594	3.3876	1.6598	6.7583	11.0563	4.2554	0.9314	-5.8056	2.7223*	4.7682**	5.1236*	5.0877*	3.9463
	(1.4715)	(2.8701)	(4.1060)	(3.6539)	(4.1878)	(4.5779)	(9.9732)	(16.5945)	(21.0432)	(17.3726)	(1.4763)	(1.7306)	(2.3766)	(2.3826)	(3.2343)
Lag of public investment shock	1.1155***	1.8725**	1.7724**	1.3249*	1.1321*	3.0673**	4.3665	4.4560	2.3832	1.0452	0.8167**	1.8706***	2.0001***	1.9217**	1.1706*
	(0.2735)	(0.6117)	(0.6750)	(0.6728)	(0.5994)	(1.2967)	(2.8457)	(2.9963)	(3.2264)	(2.8984)	(0.3102)	(0.5621)	(0.5863)	(0.6255)	(0.5776)
Lag of real GDP growth rate	-0.0011*	-0.0023**	-0.0024	-0.0053***	-0.0051**	0.0023	-0.0037	-0.0064	-0.0114	-0.0154*	0.0018***	0.0017***	0.0012	-0.0004	-0.0009
	(0.0006)	(0.0009)	(0.0017)	(0.0015)	(0.0019)	(0.0018)	(0.0041)	(0.0073)	(0.0072)	(0.0072)	(0.0005)	(0.0005)	(0.0007)	(0.0009)	(0.0012)
Constant	0.0064	0.0216	0.0324*	0.0121	0.0547***	-0.0252	0.0025	0.0081	-0.1043	-0.0447	-0.0050	-0.0034	-0.0004	-0.0072	0.0057
	(0.0045)	(0.0121)	(0.0167)	(0.0189)	(0.0128)	(0.0280)	(0.0755)	(0.0970)	(0.1157)	(0.0985)	(0.0057)	(0.0104)	(0.0137)	(0.0185)	(0.0184)
Observations	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
R-squared	0.7674	0.8013	0.8197	0.8882	0.9143	0.4540	0.4524	0.4944	0.6623	0.7455	0.6451	0.7365	0.7488	0.7652	0.7960

Source: IMF staff calculations.
Note: All regressions control for year and country fixed effects. Clustered robust standard errors in parentheses.
*p < .10; **p < .05; ***p < .01.

Online Annex 2.6. Investing in Resilience[1]

This annex discusses two areas in which investments are needed to strengthen resilience to ongoing crises—pandemic preparedness and adaptation to climate change. For pandemic preparedness, this annex estimates the costs associated with different levels of preparedness in terms of capital expenditure in public health, operating expenditure in public health, and imports of respiratory disease–related medical products. For climate change adaptation, the OECD climate-related finance flow dataset is used to estimate the aid for climate change adaptation received by countries, with a focus on low-income developing countries.

A. Pandemic Preparedness

The WHO International Health Regulation (IHR) indicators are used to assess the preparedness of the health system to confront pandemics, as suggested by the International Working Group on Financing Preparedness (2018).[2] The average IHR score summarizes 13 capacities and ranges from 0 to 100.[3] The score is used to represent preparedness, with a score of 100 indicating that the country's system has fulfilled all the requirements. The IHR score is averaged over the period from 2015 to 2017 and compared to cost data. For countries without an IHR score available for those years, the average score for 2018–19 is used instead.

Two alternative costs of preparedness are used:

(1) The public sector costs for preparedness are from the WHO's Global Health Expenditure Database.[4] Operating costs and capital expenditure costs are estimated by using, respectively, domestic general government expenditures for four health care functions,[5] and domestic public capital expenditures.[6] Annual costs are averaged over the period 2015-2017.

(2) Expenditures on medical products used to fight COVID-19 are estimated using import data for products used in the fight against respiratory diseases, based on the assumptions that these medical products are mainly manufactured in a few countries, and thus imports are a good proxy for expenditure. The products to fight COVID-19 included are respiration apparatus, cannula, X-ray equipment, thermometers, protective glasses, hand sanitizer, and surgical gloves. The annual imports (from the United Nations COMTRADE database, disaggregated at the six-digit

[1] This annex was prepared by Xuehui Han of the Fiscal Affairs Department.

[2] The IHR was introduced by the World Health Assembly in 1969. The 2005 version sets up the core capacity requirement framework for countries to prevent, detect, and rapidly respond to public health threats.

[3] According to WHO (2013, 2018), the IHR represents the commitment of governments to collectively prepare for and respond to events that may constitute a public health emergency of international concern according to a common set of rules. In 2018, WHO upgraded the IHR framework, which continued to collect data using 24 indicators across 13 capacities. The 2015–17 framework includes eight core capacities (national legislation/policy/financing, coordination, and national focal point communication, surveillance, response, preparedness, risk communication, human resource capacity, and laboratory), entry point, and four hazards (zoonotic events, food safety, chemical events, and radiation emergencies). In the 2018 upgrading, the core capacity is renamed as capacity, the capacities of response and preparedness are merged into one as the national health emergency framework, health service provision is added, and the manner of evaluation is changed from "Yes/No/Not known" to five progressive levels of capacity.

[4] The Global Health Expenditure Database is available at https://apps.who.int/nha/database.

[5] It includes expenditures on functions of curative care, medical goods, preventative care, and governance, health system and financing administration.

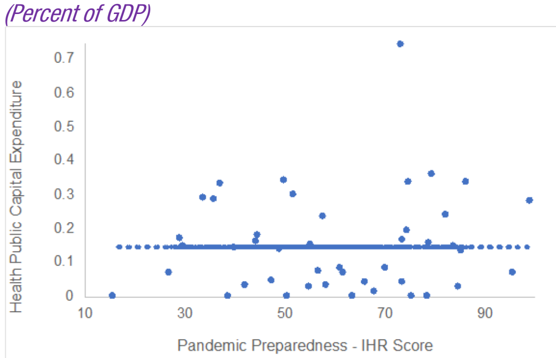
[6] For most of the countries, only fixed-capital formation is included.

HS classification) are averaged over the period from 2016 to 2018.[7] Because the six-digit classification is used, some categories might include a broader range of products (for example, cannula includes medical supplies, surgical instruments and appliance, catheters, and the like). Therefore, the estimation should be regarded as an upper-bound estimate.

Plotting public capital investment data and data on imports of respiratory medical products against the IHR index reveals different relationships. As shown in Figure 2.11 in the main text, expenditure on medical products (expressed in percent of GDP) increases with the IHR. That is, countries that are better prepared tend to spend more in terms of respiratory medical products. Such a linear relationship does not hold when using data on general public capital expenditures (Figure 2.6.1). On average, countries spend around 0.15 percent of GDP on public capital expenditure. This implies that countries with weaker preparedness (lower IHR) achieve less with the same level of capital expenditures (in percent of GDP). In other words, they spend more, on average, to achieve a given score on the IHR index, which is why the average cost per IHR is declining in the IHR (Figure 2.6.2).

Online Annex Figure 2.6.1 Health Public Capital Expenditure and World Health Organization (WHO) Index of Pandemic Preparedness

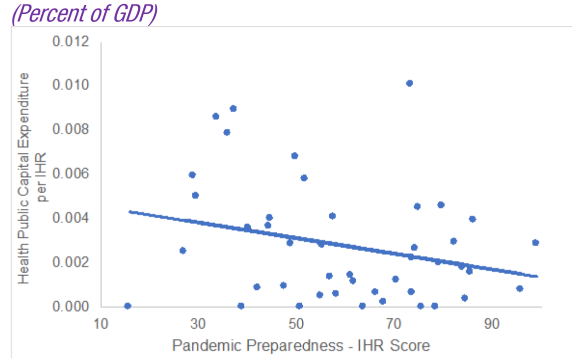
(Percent of GDP)



Sources: World Health Organzation, Index of Health Regulation (IHR); and IMF staff estimates.
Note: The figure shows no correlation between IHR index and health public capital expendiures. The same average capital expenditure is 0.15% of GDP.

Online Annex Figure 2.6.2 Health Public Capital Expenditure per Score and World Health Organization (WHO) Index of Pandemic Preparedness

(Percent of GDP)



Sources: World Health Organzation, Index of Health Regulation (IHR); and IMF staff estimates.
Note: The figure shows a negative correlation between IHR index and health public capital expendiures per score.

To investigate non-linearities in the relationship between health expenditure and pandemic preparedness, the unit cost per IHR score per capita is estimated as below:

$$c_{i,operating} = \frac{TC_{i,operating}}{IHR_i},$$

$$c_{i,capital} = \frac{TC_{i,capital}}{IHR_i},$$

where $c_{i,operating}$ and $c_{i,capital}$ are unit cost per IHR score per capita of country i of health operating expenditures and capital expenditures. $TC_{i,operating}$ and $TC_{i,capital}$ are their corresponding total expenditures per capita, and IHR_i is the IHR score (preparedness of the health system) of country i.

[7] The COMTRADE six-digit codes are respiration apparatus (901920), cannula (901839), X-ray equipment (902211), thermometers (902519), protective glasses (900490), hand sanitizer (340290), and surgical gloves (401511).

Instead of presenting the unit cost for each country, the average unit costs are presented for four different groups based on ranges of IHR preparedness scores: [0,40), [40, 60), [60, 80), and [80, 100]. The reason why the first group, [0,40), covers a larger range than the other groups is that very few countries have scores below 20. The grouping is based on the assumption that countries with similar levels of preparedness tend to have similar cost patterns compared to countries with very different preparedness. The estimates of unit costs using both data on general public health expenditures and data on imports of COVID-19-related medical products are presented in Online Annex Table 2.6.1 in both US dollars and as a share of GDP. In GDP shares, the country group with the lowest preparedness spent 0.02 percent of GDP of capital expenditure and 0.003 percent of GDP of medical product imports to achieve one score while the country group with the highest preparedness spent 0.002 percent and 0.007 percent, respectively.

Online Annex Table 2.6.1. Unit Cost per International Health Regulation Score per Capita and Share of GDP, by Score Group

	Group 1	Group 2	Group 3	Group 4
Score range	0–40	40–60	60–80	80–100
(1) Unit cost per score per capita (2017 constant US dollars)				
a. Based on Global Health Expenditure Data (GHED)				
Capital expenditures	0.23	0.11	0.13	0.12
Operating expenditures	0.65	1.50	1.36	2.29
b. Based on UN Comtrade imported medical products				
Respiratory medical products imports	0.04	0.07	0.24	0.48
(2) Unit cost per score in share of GDP (percent)				
a. Based on Global Health Expenditure Data (GHED)				
Capital expenditures	0.02	0.01	0.01	0.002
Operating expenditures	0.05	0.15	0.06	0.03
b. Based on UN Comtrade imported medical products				
Respiratory medical products imports	0.003	0.007	0.01	0.007

Source: World Health Organzation, Index of Heatlh Regulation (IHR); GHED: Global Health Expenditure Database; Comtrade dataset; and IMF staff calculations.
Note: Different country coverages for respiratory medical product imports and for capital/operating expenditures due to different data availability.

B. External Finance for Climate Adaptation

Cross-country data on external finance for climate adaptation come from the Organization for Economic Co-operation and Development's climate-related finance flow data set. Public data on adaptation flows is available from 2000; however, regular data collection for adaptation flows only started in 2010. The data cover public providers, including bilateral, multilateral, and philanthropic flows.

Until 2018, recipient countries in the low-income developing countries group were receiving 38 percent of total flows.[8] Online Annex Table 2.6.2 shows the top 10 recipient countries and subsectors in these countries in terms of accumulated flows from 2007 to 2018, as well as annual average flows for 2017–18.

For some countries, external flows for adaptation account for a significant share of total gross fixed capital formation. For example, for Uganda and Mozambique, the flows account for around 10 percent of gross fixed capital formation. Agricultural development received the largest share among sectors in the

[8] There are 52 countries in this group; Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the, Congo, Republic of, Côte d'Ivoire, Eritrea, Ethiopia, Gambia, The, Ghana, Guinea, Guinea-Bissau, Haiti, Honduras, Kenya, Kyrgyz Republic, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Moldova, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Papua New Guinea, Rwanda, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Tajikistan, Tanzania, Togo, Uganda, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe.

low-income developing countries, accounting for 9.8 percent of total flows, followed by road transport and environmental policy and administrative management.

Online Annex Table 2.6.2. The 10 Low-Income Developing Countries and Their Subsectors Receiving the Most External Adaptation Finance (in millions of 2018 USD)

Countries	Accumulated Flows 2007–18	Countries	Annual Average2017-2018	Subsectors	Accumulated Flows	Sector Share (%)
Vietnam	6003.1	Bangladesh	861.9	Agricultural development	5558.7	9.8
Bangladesh	5464.6	Ethiopia	766.2	Road transport	3713.5	6.6
Ethiopia	3766.2	Uganda	638.5	Environmental policy and administrative management	2810.1	5.0
Kenya	3255.3	Vietnam	574.0	Rural development	2713.4	4.8
Uganda	2144.3	Kenya	471.1	Agricultural water resources	2690.2	4.8
Tanzania	1887.7	Nepal	377.4	Multi-hazard response preparedness	2292.5	4.1
Mozambique	1858.5	Mozambique	371.8	Agricultural policy and administrative management	2234.1	3.9
Senegal	1842.1	Myanmar	349.5	Water supply - large systems	2148.8	3.8
Cambodia	1811.2	Nigeria	343.9	Food assistance	2059.0	3.6
Nepal	1769.5	Senegal	299.2	Water sector policy and administrative management	1682.5	3.0

Sources: OECD; and Development; and IMF staff calculations.

Online Annex 2.7. Estimating the Adaptation Costs of Investing in the Resilience of Physical Assets[1]

While many important and necessary adaptation policies are needed (for example, strengthening early warning systems, agriculture systems, and water resources management), investing in infrastructure resilience is by far the costliest (Global Commission on Adaptation 2019). This annex focuses on two natural hazards (floods and cyclones) and three types of adaptation costs: (1) retrofitting existing economic assets exposed to natural hazards to improve their resilience, (2) upgrading projected investment in all sectors to improve resilience to natural hazards, and (3) building coastal protection infrastructure. The overall cost estimates for public investment for climate change adaptation by country and by income group are presented in Figure 2.1.1 in the main text.

Upgrading and Retrofitting Costs

Upgrading and retrofitting costs are estimated using a bottom-up approach based on country exposure to natural hazards and the additional costs that would be incurred to make exposed assets more resilient. The analysis uses a new database in which the shares of exposed assets by country are inferred from cross-referencing two detailed global maps, one of natural hazards and another of road and railway asset data (Koks and others 2019). The degree of asset exposure is adjusted to reflect higher protection standards in upper-middle-income and high-income countries.[2]

The incremental costs of making exposed assets more resilient are estimated using the average values corresponding to the set of technical options from Miyamoto International (2019). Though the technical solutions are economically sensible, they do not guarantee that assets cannot be damaged by natural hazards and do not include all possible options to reduce risks, including more cost-effective alternatives or more expensive options to reduce risks further.[3] Based on the exposure and incremental cost measures, the following are estimated:

- *Upgrading costs* are computed as the annual investment projections on average over 2020–25, multiplied by the estimated share of exposed assets, and by a unit cost of 15 percent (Rozenberg and Fay 2019). Hence, the average exposure of future projects is assumed to be the same as the exposure of existing assets.[4] Public and private investment projections are from the April 2020 *World Economic Outlook*. When projections are unavailable, it is assumed that future investment-to-GDP ratios remain constant at the last observed level in the IMF's 2019 Investment and Capital Stock Dataset.
- *Retrofitting costs* are computed as the public capital stock (from the IMF's 2019 Investment and Capital Stock Dataset), multiplied by the estimated share of exposed assets and by a unit cost of 50 percent (Rozenberg and Fay 2019). The total costs are annualized by assuming constant disbursement in percent of GDP over the next 10 years. Note that it may be more cost-effective

[1] This annex was prepared by Matthieu Bellon of the Fiscal Affairs Department.

[2] The protection standards in upper middle-income and high-income countries are from Rozenberg and Fay (2019, Table 5.2).

[3] Many high-income countries like Japan sometimes implement technical solutions that go beyond—and are more expensive than—the set of solutions considered in Miyamoto International (2019).

[4] This assumption is supported by historical evidence of the extreme persistence of the geographic distribution of human activity, even amid catastrophic shocks (Davis and Weinstein 2002).

to abandon some exposed assets or tear them down and rebuild them better. The unit cost of 50 percent would also correspond to an average view between these cases.

Coastal Protection Costs

Coastal protection costs are the as-yet-unreported country-level estimates corresponding to the global levels presented in Rozenberg and Fay (2019). The annual investment and maintenance costs are reported for the economically optimal level of protection, defined as the level that minimizes the sum of protection costs (capital and maintenance) and residual flood damage to assets up until 2100. The full level of protection is assumed to be reached by 2030, with disbursements spread equally over the years. The estimation uses the state-of-the-art Dynamic Interactive Vulnerability Assessment (DIVA) climate model and new projections of coastal protection construction costs (Nicholls and others 2019).[5] When considering the different assumptions regarding socioeconomic projections, unit costs, and greenhouse gas concentration pathways, average specifications are used.

[5] DIVA is a global model of coastal systems that assesses biophysical and socioeconomic consequences of sea-level rise and socioeconomic development, taking into account the following key impacts: coastal erosion (both direct and indirect), coastal flooding (including rivers), wetland change, and salinity intrusion into deltas and estuaries.

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