Forecasting Current-Quarter U.S. Exports Using Satellite Data

By Jun Nie and Amy Oksol

Forecasting export growth can be challenging. Export growth depends heavily on demand from foreign countries, which is difficult to directly measure. In practice, forecasters usually approximate strength in foreign demand through growth in foreign gross domestic product. But this approach has two problems. First, GDP data are released with a significant delay—for most countries, one to two quarters. Second, the quality of foreign GDP data varies. In some developing economies, GDP is poorly measured and thus may not be helpful in gauging those economies' true incomes (Johnson and others 2009; Deaton and Heston 2010).

Recent research suggests nighttime lights data from satellites may be able to overcome both of these challenges, making them potentially useful in forecasting exports. Henderson and others (2012) show nighttime lights are useful in measuring GDP, as the amount of light in a given area is positively correlated with income in that area. In addition, satellite data are likely more reliable than countries' published measures. Furthermore, recent improvements in satellite technology have made satellite data available at higher frequencies than GDP data: monthly satellite data have been available since 2012, and daily data have been available since 2017. The increased frequency of these new

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data suggest nighttime lights could improve export forecasting based on foreign GDP. However, to the best of our knowledge, these data have not yet been tested in forecasting U.S. exports.

In this analysis, we use nighttime lights data to forecast current-quarter U.S. export growth. We focus on current-quarter forecasts because a better estimate of current exports will establish a base for forecasting future exports. We find nighttime lights data are helpful overall in forecasting current-quarter U.S. export growth, largely due to more frequent data. In particular, we find that using monthly nighttime lights data generates a smaller forecast error than using quarterly foreign GDP. When using quarterly data for both lights and foreign GDP, however, GDP data outperform lights data.

Section I introduces the nighttime lights data from satellites and shows the relationship between the nighttime lights index and U.S. exports. Section II evaluates the performance of the lights data in forecasting U.S. exports.

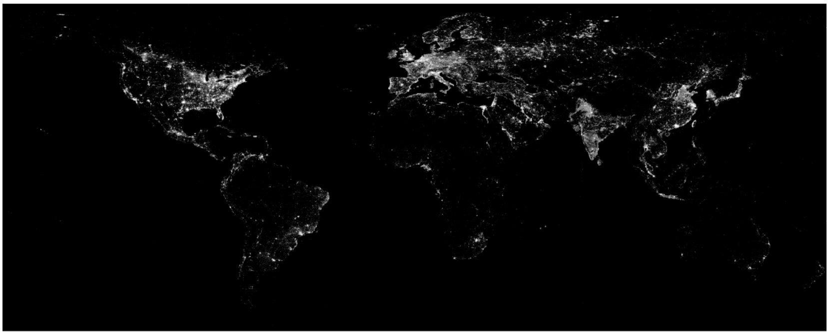
I. Introducing Nighttime Lights Data from Satellites

Nighttime lights as viewed from satellites make up a unique dataset that provides information on nearly every place on earth. The data are publicly available through the Earth Observation Group at the National Oceanic and Atmospheric Administration (NOAA) and are provided in the form of satellite images. Figure 1 shows a sample image from the dataset.[1] Satellite cameras take pictures of the entire planet at night (so lights can be better seen) and filter the images for various anomalies such as clouds and fires.

Each image is very detailed and made up of pixels approximately 1 km^2 in size that hold a luminosity value ranging from 0 to 63, with 0 being unlit and 63 being maximum light. This detail allows us to construct a numerical lights index for a particular region using ArcGIS software, which can extract the amount of nighttime light in that region in a given period. Each of these luminosity values can be summed across cities, regions, countries, or other geographic areas to get a total luminosity value at a certain point in time.

As satellite technology has evolved, data have become available at higher frequencies. Nighttime lights data are currently available at an annual frequency from 1992 to 2013, at a monthly frequency from April 2012 to the present, and at a daily frequency beginning in 2017.

Figure 1
Satellite Image of Nighttime Lights



Sources: NOAA Version 4 DMSP-OLS Nighttime Lights Time Series and authors' calculations.

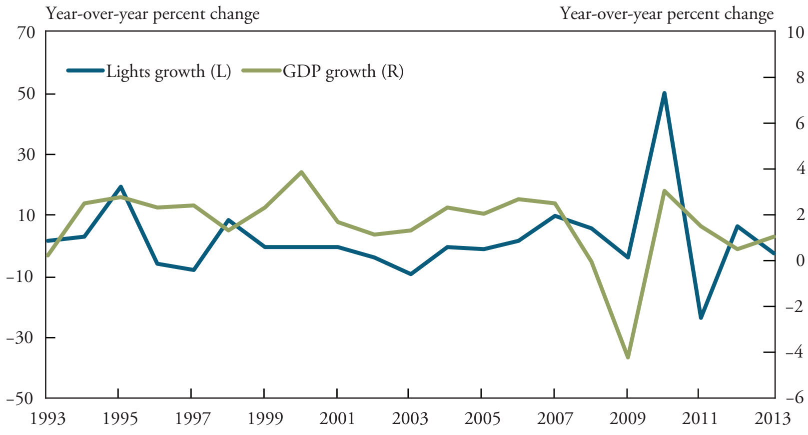
Some researchers have used annual nighttime lights data to study GDP growth, as nighttime lights in a given region are positively correlated with changes in income in that region. The intuition for this relationship is relatively straightforward: as a region becomes richer, consumer spending and business investment rise, and more nighttime lights are likely to appear. Nighttime lights data can be especially useful when studying developing economies, which may have less reliable national statistics. Bhandari and Roychowdhury (2011), for example, show that nighttime lights serve as a relatively decent proxy for local economic growth in India. And Clark and others (2017) use nighttime lights to estimate economic growth in China, finding that Chinese growth may be greater than what is reported in official statistics.

To illustrate the relationship between nighttime lights and GDP, we construct an annual aggregate lights index for both advanced economies and developing economies from 1992 to 2013 and compare lights growth with GDP growth. Panel A of Chart 1 shows annual lights growth and annual GDP growth for the advanced economies, while Panel B shows the corresponding data for developing economies. The chart shows that lights growth (blue lines) in general tracks GDP growth (green lines), though the correlation is not very strong. In addition, the chart shows that lights growth, which is plotted on the left axis, is much more volatile than GDP growth, which is plotted on the right. This is consistent with the findings of previous research such as Henderson and others (2012)—specifically, that nighttime lights contain useful

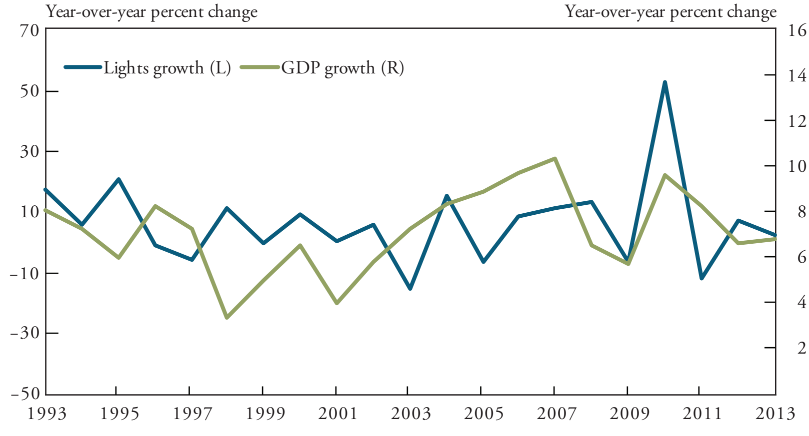
Chart 1

Light Index and GDP for Selected Countries

Panel A: Advanced Economies



Panel B: Developing Economies



Sources: NOAA Version 4 DMSP-OLS Nighttime Lights Time Series, Statistics Canada, Instituto Nacional de Estadística Geografía e Informática, Danmarks Statistik, Institut Nat de la Statistique et des Etudes Economiques, Deutsche Bundesbank, Istituto Nazionale di Statistica, Statistisk Sentralbyra, Statistiska Centralbyran, Turkish Statistical Institute, Office for National Statistics of the UK, China National Bureau of Statistics, Census and Statistics Department of Hong Kong, Biro Pusat Statistik, Cabinet Office of Japan, Bank of Korea, National Statistical Coordination Board, Department of Statistics of Singapore, and authors' calculations. GDP data accessed through Haver Analytics.

information about GDP, though lights and GDP differ conceptually and in the way they are measured.

Nighttime lights' close relationship with GDP suggests they could also be useful in estimating a country's demand for foreign goods and services—and, therefore, U.S. exports to that country. Building on previous research, we compute the correlations between exports and lights, exports and GDP, and GDP and lights over time across a sample of 22 countries. Table 1 reports the correlations for advanced and developing economies. They are reported separately for two reasons. First, developing economies have been shown to have less reliable GDP measures. Second, advanced and developing economies have different influences on U.S. exports (Nie and Taylor 2013). The 22 countries in our sample, listed in Appendix A, together account for about 70 percent of U.S. exports.[2] The sample period is 1992–2016.

The results in Table 1 suggest that U.S. export growth is more correlated with foreign GDP growth than with nighttime lights growth. However, differences in the correlations for advanced and developing economies suggest the lights index is still valuable. Although the correlation between U.S. export growth and foreign lights growth is about the same in advanced economies (0.29) and developing economies (0.28), the correlation between foreign GDP growth and U.S. export growth is much higher in advanced economies (0.79) than in developing economies (0.49). One possible explanation for this difference is that GDP is better measured in advanced economies relative to developing economies. Consistent with this explanation, the correlation between GDP growth and lights growth is also stronger in advanced economies (0.17) than in developing economies (0.14), although the difference is quite small and not statistically significant.[3]

To further explore the relationship between the foreign lights index and U.S. exports, we estimate a panel regression model with U.S. exports to individual countries as the dependent variable and the key variable of interest, lights, as an explanatory variable. Our sample period is 1992–2013, which covers all available annual data. We control for a wide range of country-specific factors, such as the foreign currency/dollar exchange rate, the share of urban population in total population, the employment share of the agriculture sector, and the employment share of the manufacturing sector. These variables are commonly used

Table 1
Correlation between Exports, Lights, and GDP

Variables	Advanced	Developing
Export growth and lights growth	0.29	0.28
Export growth and GDP growth	0.79	0.49
GDP growth and lights growth	0.17	0.14

Sources: IMF, NOAA Version 4 DMSP-OLS Nighttime Lights Time Series and VIIRS Day/Night Band Nighttime Lights, Bureau of Economic Analysis, World Bank, Statistics Canada, Instituto Nacional de Estadística Geografía e Informática, Danmarks Statistik, Institut Nat de la Statistique et des Etudes Economiques, Deutsche Bundesbank, Istituto Nazionale di Statistica, Statistisk Sentralbyra, Statistiska Centralbyran, Turkish Statistical Institute, Office for National Statistics of the UK, China National Bureau of Statistics, Census and Statistics Department of Hong Kong, Biro Pusat Statistik, Cabinet Office of Japan, Bank of Korea, National Statistical Coordination Board, and Department of Statistics of Singapore. GDP and export data accessed through Haver Analytics.

in related research and relevant for either export activities or the intensity of lights in a region. We also include country fixed effects to capture other country-specific factors that our specification does not explicitly include. In addition, we include a group indicator variable to allow the effects of lights on exports to differ in advanced and developing economies. As a comparison, we also estimate two similar regression models which either replace light growth with GDP growth or add GDP growth to the regression model. Key results from the regressions are reported in Table 2.

The results show a statistically significant association between nighttime lights growth and U.S. export growth. Column 1 shows the association is stronger for developing economies than for advanced economies. In particular, a 1 percentage point increase in lights growth is associated with a 0.103 percentage point increase in U.S. export growth to advanced economies; the associated change in export growth to developing economies is 0.344 percentage point (0.103+0.241). In contrast, column 2 shows that when we incorporate GDP growth in the regression, the difference between developing economies and advanced economies is not statistically significant. This difference highlights the importance of separating the two groups of countries when using lights data to forecast export activities. Finally, column 3 shows that when we control for GDP growth, the relationship between lights growth and export growth is still significant (particularly for developing economies), suggesting the lights data provide additional information that helps forecast exports.

Table 2
Regression Results (Annual Data)

Dependent variable: U.S. export growth	(1) Coefficients	(2) Coefficients	(3) Coefficients
Lights growth	0.103* (0.058)		0.048 (0.058)
Lights growth*group indicator (1=developing economies)	0.241*** (0.062)		0.187*** (0.056)
Foreign GDP growth		1.680*** (0.558)	1.70*** (0.567)
Foreign GDP growth*group indicator (1=developing economies)		0.567 (0.582)	0.281 (0.603)
Controls	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2	0.105	0.134	0.145

* Significant at the 10 percent level
*** Significant at the 1 percent level
Note: Controls include the exchange rate, urban population as a percentage of total population, manufacturing employment as a percentage of total employment, agriculture employment as a percentage of total employment, and year fixed effects.

Together, these findings suggest that GDP data are more valuable in forecasting U.S. exports than lights data when GDP data are available and well-measured. However, lights data are likely to be more valuable when GDP data are less precisely measured or available with a delay. In practice, data on foreign GDP growth are usually released with a delay of one to two quarters. The availability of monthly lights data in real time may make lights growth more useful than GDP growth in forecasting current-quarter exports.

II. Comparing Forecast Performance with Nighttime Lights and GDP Data

We use two approaches to test the performance of more frequent nighttime lights data in forecasting current-quarter U.S. export growth.[4] In the first approach, we estimate three different forecasting models using data at a quarterly frequency. As the data are aggregated to a quarterly frequency, we do not use any within-quarter information in this approach. However, in the second approach, we estimate similar models at a monthly frequency, which allows us to use within-quarter information about nighttime lights. This monthly approach cannot be applied to GDP data as GDP data are only available at quarterly or annual frequencies. In each approach, we compare the forecasts with those from a random-walk model—a simple statistical model that forecasts current-quarter U.S. exports based solely on the previous quarter's exports. The random-walk model is a commonly used benchmark in research on forecasting. Appendix B provides technical details on the different models used for each approach.

Quarterly approach

In our quarterly approach, we compare the results from three forecasting models of current-quarter U.S. export growth: one specified using GDP growth, one specified using nighttime lights growth, and a random walk. Because the relationships between U.S. export growth, lights growth, and GDP growth differ in developing and advanced economies, we estimate the first two models separately for developing and advanced economies and then combine the forecasts from the two groups to provide overall forecasts for total U.S. export growth.[5]

Our GDP growth specification links growth in U.S. exports to a given country in the current quarter to GDP growth in that country in the previous quarter. In this specification, we include the percentage change in the destination country's exchange rate in the previous quarter to control for the effects of price changes on exports.[6] We use the previous quarter's percentage change in GDP and the exchange rate because current-quarter data are not available at the time forecasts are conducted. To capture the persistence of export growth—in other words, to account for the influence of past values of export growth on its current value—we also include the previous quarter's growth in U.S. exports in the model.

In the lights specification, we replace the destination country's GDP growth with its growth in nighttime lights. Because nighttime lights data are available at the monthly frequency, we aggregate our monthly nighttime lights index to the quarterly frequency. Because the nighttime lights data are not seasonally adjusted, we measure all growth rates as the percentage change from the previous year.[7] We use the previous quarter's growth in GDP, the exchange rate, and lights because data for the current quarter—that is, the quarter in which the forecast is conducted—are unavailable.[8] Following Nie and Taylor (2013) and Sly (2016), we use panel regressions, a statistical method that allows us to examine data across two dimensions—in this case, countries and time—for these two specifications.[9]

Finally, the random-walk model forecasts export growth by assuming that U.S. export growth in the current quarter is the same as in the previous quarter.

We compare forecasts by taking the average of each model's performance in the most recent eight quarters. To be precise, we estimate each model using data from the second quarter of 2012 (when quarterly lights data became available) to the third quarter of 2015. We then use this model to conduct eight "current-quarter" forecasts from 2015:Q4 to 2017:Q3. To evaluate the model's forecasting accuracy, we compare the root-mean-square error (RMSE), a common forecasting metric of the average deviation of the forecast from the actual value.

Table 3 reports the relative RMSE from different specifications for all countries and for advanced and developing economies separately. For ease of comparison, we normalize the RMSE for the random-walk model to be 1 for each group. If one of the other two model specifications has an RMSE above 1, it "loses" to the random walk—that is, it has a larger forecast error. Likewise, if one of the specifications has an RMSE below 1, it "beats" the random walk—that is, it has a smaller forecast error. We obtain the RMSEs for the group labeled "All" by aggregating the forecasts for individual countries in the groups of advanced and developing economies to construct a forecast for total U.S. exports. Note that comparing values across columns in Table 3 is meaningless, as each column has been normalized to the corresponding RMSE in the random-walk specification (third row).[10]

At the quarterly frequency, the lights specification does not beat either the GDP specification or the random walk in forecasting U.S. exports to the "Advanced" or "All" groups. The forecast error for total export growth (all countries) is slightly smaller in the GDP specification, at 1.31, than in the lights specification, at 1.39. This confirms our previous finding that when data are available for GDP and lights at the same frequency, forecasts using GDP perform better than those using lights. However, as we only use the previous quarter's GDP and lights data, the quarterly forecast based on lights ignores some available within-quarter lights data.[11] In addition, the random-walk model beats

Table 3
Quarterly Forecast Comparison (Normalized RMSE)

Model specification	All	Advanced	Developing
GDP	1.31	0.95	0.98
Lights	1.39	1.25	0.75
Random walk	1.00	1.00	1.00

Note: For every country group, the table shows the RMSE of each model relative to the RMSE of the random walk model.
Sources: International Monetary Fund, NOAA, VIIRS Day/Night Band Nighttime Lights, Bureau of Economic Analysis, World Bank, Statistics Canada, Instituto Nacional de Estadística Geografía e Informática, Danmarks Statistik, Institut Nat de la Statistique et des Etudes Economiques, Deutsche Bundesbank, Istituto Nazionale di Statistica, Statistisk Sentralbyra, Statistiska Centralbyran, Turkish Statistical Institute, Office for National Statistics of the UK, China National Bureau of Statistics, Census and Statistics Department of Hong Kong, Biro Pusat Statistik, Cabinet Office of Japan, Bank of Korea, National Statistical Coordination Board, Department of Statistics of Singapore, and authors' calculations. GDP, exchange rate, and export data accessed through Haver Analytics.

both the GDP specification and the lights specification in forecasting export growth across all countries included in the sample.[12]

Interestingly, the lights specification beats the GDP specification in forecasting exports to developing economies. In particular, the lights specification generates a forecast error of 0.75, much smaller than the 0.98 forecast error for the GDP specification. Moreover, the lights specification produces a more accurate forecast than the random walk, whereas the forecast based on GDP data is roughly as accurate as the random-walk forecast. Together, these results suggest lights data may be more beneficial in generating forecasts for developing economies, as GDP may not be measured as precisely in developing economies as in advanced economies.

Monthly approach

Our monthly approach allows us to incorporate the largest potential advantage of using lights data to forecast exports: their timeliness. In the quarterly approach, we converted monthly lights data to quarterly data and did not use any within-quarter information about nighttime lights. To better exploit the advantages of the nighttime lights dataset, we next estimate the lights specification at a monthly frequency. As monthly GDP data are unavailable, we cannot estimate the GDP specification using the monthly approach. Instead, we compare the forecasts from the monthly lights specification to those from the quarterly GDP specification.

Using monthly data to forecast current-quarter exports requires us to identify how many months of data are available at the time the forecast is made. In some cases, forecasters might have export data for only the first month of the current quarter; in others, they might have data for both the first and second months of the quarter. We test our lights model's performance in both cases. In the "early-quarter forecast," we include export data for only the first month of the current quarter in our forecast. In the "late-quarter forecast," we include export data for two months of the current quarter.[13]

Panels A and B of Table 4 illustrate the data available in each forecast assuming the current quarter is the first quarter, Q1, of a given year. The early-quarter forecast includes export data up to January and lights and exchange rate data up to February. This data allows us to forecast export growth in February and March. To forecast exports in February, we plug the February lights and exchange rate data into our estimated monthly model (see Appendix B). To forecast exports in March, we perform the same exercise but assume the March lights and exchange rate data are the same as in February.[14] We calculate export levels in February and March based on the forecast growth rates. We then combine these data with the data for January to construct an export growth forecast for Q1. The forecast procedure for the late-quarter forecast is similar but simpler, as we only need to forecast March exports.

To evaluate the monthly lights model's performance, we first compare the RMSEs of the early- and late-quarter forecasts to those from the random-walk model. As in the quarterly approach, we normalize the forecast errors for the random-walk model to be 1.

The results from Panel A of Table 5 show that early-quarter forecasts generated from the lights specification have substantially smaller forecast errors than those generated from the random-walk model. This is in sharp contrast with the comparison in the quarterly approach, which shows the random-walk model does a better job in forecasting total export growth than the lights model. This comparison suggests that using within-quarter information substantially improves the forecasting power of the lights specification as measured by RSME. In addition, Panel B shows that the relative advantage of using lights data, measured by the difference in the normalized RMSEs between the lights specification and the random-walk specification, is smaller in the late-quarter

Table 4
Data Availability for Forecasting

Panel A: Early-Quarter Forecast

Available data	Q1 Jan.	Q1 Feb.	Q1 March
Exports	X		
Lights	X	X	
Exchange rate	X	X	

Panel B: Late-Quarter Forecast

Available data	Q1 Jan.	Q1 Feb.	Q1 March
Exports	X	X	
Lights	X	X	X
Exchange rate	X	X	X

Table 5
Monthly Forecast Comparison (Normalized RMSE)

Panel A: Early-Quarter Forecast

Model specification	All	Advanced	Developing
Lights	0.48	0.63	0.52
Random walk	1.00	1.00	1.00

Panel B: Late-Quarter Forecast

Model specification	All	Advanced	Developing
Lights	0.98	0.54	0.98
Random walk	1.00	1.00	1.00

Note: For every country group, the table shows the RMSE of each model relative to the RMSE of the random-walk model.
Sources: International Monetary Fund, NOAA VIIRS Day/Night Band Nighttime Lights, and authors' calculations. Exchange rate and export data accessed through Haver Analytics.

Table 6
Overall Forecast Comparison (RMSE)

Model specification	All	Advanced	Developing
Random walk: quarterly	2.20	3.23	4.13
GDP: quarterly	2.89	3.06	4.06
Lights: quarterly	3.06	4.05	3.11
Random walk: monthly	2.28	2.14	3.27
Lights: monthly	1.33	1.28	2.00

Note: The RMSE for the monthly light model is the average of the RMSEs in the late and early forecasts.
Sources: International Monetary Fund, NOAA VIIRS Day/Night Band Nighttime Lights, Bureau of Economic Analysis, World Bank, Statistics Canada, Instituto Nacional de Estadística Geografía e Informática, Danmarks Statistik, Institut Nat de la Statistique et des Etudes Economiques, Deutsche Bundesbank, Istituto Nazionale di Statistica, Statistisk Sentralbyra, Statistiska Centralbyran, Turkish Statistical Institute, Office for National Statistics of the UK, China National Bureau of Statistics, Census and Statistics Department of Hong Kong, Biro Pusat Statistik, Cabinet Office of Japan, Bank of Korea, National Statistical Coordination Board, Department of Statistics of Singapore, and authors' calculations. GDP, exchange rate, and export data accessed through Haver Analytics.

forecast than in the early-quarter forecast. For example, the forecast errors from the lights specifications are only slightly lower than the forecast errors from the random-walk specifications for the "all" group and for developing economies (both are 0.98 versus 1).[15] This is not surprising because in the late-quarter forecast, we have two months of data and thus only need to forecast one additional month to construct the quarterly export growth, while in the early-quarter forecast we need to forecast two months of exports.[16]

To evaluate the performance of our monthly lights specification relative to our quarterly GDP specification, we next compare the non-normalized forecast errors.[17] Table 6 shows the average percentage point deviation of each forecast from the actual data. The monthly specification with lights data beats all other model specifications, generating the smallest forecast errors for all three groups: all, advanced economies, and developing economies.[18] Moreover, the difference between the forecast errors generated using quarterly or monthly lights data is substantial. For example, the average forecast error using quarterly lights data is 3.06 percentage points; using monthly lights data, the forecast error drops to only 1.33 percentage points. In contrast, the random-walk model shows almost no improvement using monthly data, indicating that more export data alone do not necessarily improve forecasts.[19]

Overall, the results in Table 6 suggest monthly lights data offer significant advantages over quarterly GDP data in forecasting U.S. exports.

III. Conclusions

Forecasting current-quarter export growth can be challenging without accurate, timely measures of foreign demand. Although GDP growth is often used to approximate foreign demand, nighttime lights data from satellite images offer forecasters an attractive alternative. In particular, nighttime lights data are released more frequently and closer to real time than GDP data and are less likely to be mismeasured.

We construct a lights index for major U.S. trading partners and compare forecasts using this index to forecasts using GDP data as well as to forecasts generated from a random walk. We find that a forecasting model using monthly lights data generates significantly lower forecasting errors than a quarterly GDP model. Our comparison of model performance suggests that monthly lights data could improve the accuracy of export forecasts before quarterly GDP data are released.

More frequent lights data could offer further improvements. Although we focus on monthly data in our analysis, daily lights data became available beginning in 2017. Future forecasting models may be able to exploit this data to provide increasingly accurate forecasts of export growth.

Appendix A

Countries in the Analysis

Table A-1
Advanced and Developing Economies

Advanced	Developing
Austria	China
Canada	India
Denmark	Indonesia
France	Mexico
Germany	Philippines
Hong Kong	Singapore
Israel	Turkey
Italy	
Japan	
South Korea	
Norway	
Portugal	
Spain	
Sweden	
United Kingdom	

Note: We treat Hong Kong and mainland China separately because they show different dynamics in their imports from the United States.

Appendix B

Model Details

This appendix lists the main model specifications used in the forecast comparison for both the quarterly and monthly approaches to forecasting with nighttime lights data. In the quarterly approach, we use the previous quarter's growth rates of all variables on the right hand side of the models, because current-quarter GDP, lights, and exchange rate data are not available. In the monthly approach, we use lights but not GDP as an explanatory variable, as GDP data are not published at a monthly frequency.

As lights data are not seasonally adjusted, we define the growth rate as the percentage change from a year earlier for all variables. We use this definition to construct levels in forecasts and then convert monthly levels to quarterly levels to be comparable with other forecasts.

Quarterly approach

(1) Random-walk model:

$$export\_growth_{i,t} = export\_growth_{i,t-1} + \mu_{i,t}$$

(2) Lights model:

$$\begin{aligned} export\_growth_{i,t} \\ &= \beta_0 + \beta_1\, light\_growth_{i,t} + \beta_2 exchange\_growth_{i,t-1} \\ &+ \beta_3\, export\_growth_{i,t-1} + \mu_{i,t} \end{aligned}$$

(3) GDP model:

$$\begin{aligned} export\_growth_{i,t} \\ &= \beta_0 + \beta_1\, GDP\_growth_{i,t-1} + \beta_2 exchange\_growth_{i,t-1} \\ &+ \beta_3\, export\_growth_{i,t-1} + \mu_{i,t} \end{aligned}$$

Monthly approach

(4) Random-walk model:

$$export\_growth_{i,t} = export\_growth_{i,t-1} + \mu_{i,t}$$

(5) Lights model:

$$export\_growth_{i,t} = \beta_0 + \beta_1\, light\_growth_{i,t} + \beta_2 exchange\_growth_{i,t} + \beta_3\, export\_growth_{i,t-1} + \mu_{i,t}$$

Endnotes

[1]Due to different time zones, the images for different regions are taken at different times and then aggregated together to form a single image of the entire globe.

[2]We select the same countries as in Nie and Taylor (2013) unless the data are not available. We omit Russia because growth in U.S. exports to Russia is several times more volatile than for other countries in the sample period (1992–2016).

[3]We test the difference between the two correlations using Fisher's z-transformation, a statistical tool designed to test the difference between correlations in two groups. Based on this test, we cannot reject the hypothesis that the two correlations are the same.

[4]As available daily data are still limited, we do not use them in this analysis.

[5]We aggregate levels first and then calculate the growth rate for total U.S. exports. Specifically, based on the forecast growth rates of U.S. exports to developing economies and advanced economies respectively, we calculate the corresponding export levels to these two groups of countries. We then add the two levels to get the total U.S. export level. Finally, we calculate quarterly export growth based on the aggregate export levels. We also estimate a unified model that includes both advanced and developing economies. We use an indicator variable to distinguish the effects of lights growth or GDP growth on export growth between the two groups of countries. We find this model produces a small improvement in forecast errors but does not change our main results in the forecast comparison. In addition, the coefficient associated with the indicator variable is not statistically significant. In another robustness check, we remove Canada from the advanced economies group and Mexico from the developing economies group. The key results hold, suggesting our results are not driven by a couple of major U.S. trading partners.

[6]Export growth and GDP growth are measured in real terms in this analysis. However, exchange rates for different foreign countries are measured in nominal terms due to the difficulty in measuring relative price movements between the United States and foreign countries. In addition, price indexes used in constructing real exchange rates are released with a delay.

[7]Though our models use growth from over a year ago, we translate all our forecasts into quarter-over-quarter growth, which is a more common format for comparing macroeconomic forecasts. In particular, we first forecast the level of each variable using its predicted growth from one year ago. Then we use the predicted level to calculate quarter-over-quarter growth in the variable. For example, to forecast the growth rate of U.S. exports in the second quarter of 2016 relative to the first quarter of 2016, we first use our model to forecast the export growth rate in the second quarter of 2016 relative to the second quarter of 2015. Based on this year-over-year growth and the export level in the second quarter of 2015, we calculate the export level in the second quarter of 2016. Once we have

the level in the second quarter of 2016, we can calculate the growth rate from the first quarter to the second quarter of 2016.

[8]In a robustness check, we also estimate a model specification that uses current growth in GDP, the exchange rate, and lights to explain current export growth. Using this alternative specification does not qualitatively change our main results.

[9]Sly (2016) uses levels in estimating the models, while we use growth rates. We use growth rates mainly because our nighttime lights data are not seasonally adjusted and our interest is producing forecasts for export growth.

[10]For comparison across columns, see Table 7.

[11]We assume GDP data for the previous quarter are available for all foreign countries. In reality, this may not be true, as some countries' GDP data are released with a delay of two quarters. In other words, the performance of the GDP specification could be overestimated.

[12]Although the GDP model generates a larger forecast error than the random-walk model for "all" countries, the GDP model generates a slightly smaller forecast error than the random-walk model for the "advanced" and "developing" groups of countries. This result may seem confusing but is possible due to the aggregation process. For example, suppose the GDP model overestimates export growth for both groups of countries, while the random-walk model overestimates for one group and underestimates for the other group. Under these circumstances, the random-walk model could lead to a smaller forecast error for total exports when the two groups are aggregated.

[13]In theory, we can include another example which assumes forecasters have one month of lights data and no exports data at all for the current quarter. Including this example does not change our main conclusion. However, we omit it from our analysis because in practice, forecasters start to forecast the current quarter only when the previous quarter's data are released, which is usually in the second month of the current quarter.

[14]We also estimate an alternative specification that uses the previous month's growth in lights and the exchange rate instead of the current month's values. In that specification, we can directly use the previous month's data to forecast the current month's export growth. Using this specification does not alter our main conclusions.

[15]The ratio for the advanced group, 0.54, is much smaller mainly because the decline in the absolute forecast error from the early-quarter forecast to the late-quarter forecast is quite small for the random-walk specification. More specifically, the forecast errors for the late-quarter forecasts in the random-walk specification decline by about 75 percent for the all group and the developing group but only by about 50 percent for the advanced group. As a result, the relative forecast error for the lights specification is smaller in the advanced group just because of a much larger denominator.

[16]Again, the normalized RMSEs cannot be directly compared across tables because they are not normalized by the same base value. For example, the absolute

level of RMSE in the late-quarter forecast (Panel B of Table 5) is generally smaller than in the early-quarter forecast (Panel A of Table 5).

[17]The forecast errors across different specifications are comparable because we convert the monthly forecasts to quarterly measures.

[18]The forecast error for the monthly light specification in this table is the average forecast error of the early-quarter forecast and the late-quarter forecast.

[19]The lights data are not seasonally adjusted (see Appendix B), so all variables' growth rates are defined as the percentage change from 12 months earlier. We conduct robustness checks using three-month and six-month growth rates, which do not qualitatively change our main results.

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