The Effect of Foreign Investment on Asian Coal Power Plants

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Asia has built 90% of new coal-fired capacity worldwide in the past 20 years, attracting billions of dollars of foreign investment. This paper explores how such foreign investment has affected the environmental performance of a set of 2108 Asian coal power plants. The findings suggest that foreign-funded power plants are on average 3.4% cleaner in terms of carbon dioxide (CO_2) emissions intensity than their domestically funded counterparts, with an effect that varies by foreign country, from 8.9% cleaner (South Korea) to 2.0% dirtier (Russia). Better technology (heat rate) explains 96% of this improved environmental performance, while cleaner coal (emission factor) explains the remaining 4%. The environmental performance of foreign-funded coal power plants has only a negligible spillover effect on the performance of domestically funded plants. Although foreign investment slightly reduces CO_2 emissions per unit of electricity, overall, it increases global reliance on coal, thus undermining global ambitions to curb greenhouse gases.

Keywords: coal power plants; FDI; spillover effect; carbon dioxide emissions

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1. Introduction

Coal-fired power plants, generating 38.5% of the global electricity supply, are the largest contributors to CO_2 emissions in the power sector (IEA, 2018). They are relatively cheap to build and run in most developing countries. As a result, these plants represent the tradeoff between two important Sustainable Development Goals (SDGs): affordable energy and climate action. Although few coal plants are being built in OECD countries, there has been a vast expansion of coal plants in Asia, which accounts for 90% of the new coal-fired capacity worldwide over the past 20 years (IEA, 2019). Foreign investors, most of them from developed countries, have played a key role in this development: they have invested over $62 billion (54 GW) in Asia's coal power deployment, and have planned another 44 GW of capacity through 2050 (End Coal, 2021). The question therefore arises whether these investors could deliver affordable energy at lower climate costs by bringing advanced clean technologies to developing countries while also improving energy access. This empirical study helps answer whether foreign-financed plants are cleaner or dirtier than their domestic counterparts, as well as whether Asia benefits from the efficient technologies of foreign firms.

The literature has suggested three ways that foreign investment could affect emissions in various sectors: by influencing environmental standards, by improving the performance of supported projects, and through spillover effects. The first body of research suggests that countries may lower their pollution standards in order to attract foreign investment – a "Pollution Haven" "race to the bottom" effect (Arden-Clarke, 1993; Porter, 1999; Esty, 2001). This influence would tend to increase emissions per plant. Many studies have tested this hypothesis but have failed to find supporting evidence (He, 2006; Levinson & Taylor, 2008; Wagner & Timmins, 2009). On the more positive side, foreign direct investment could attract more efficient technology and companies with higher internal environmental standards leading to lower emissions per plant – a Pollution Halo effect (Zarsky, 1999; Garcia-Johnson, 2000; Wang and Jin, 2002; Lovely and Popp, 2011; Cole et al., 2017). Finally, a third strand in the literature argues that foreign companies would bring knowledge and technology spillovers that would help domestic firms improve their efficiency (Albornoz et al., 2009; Sari et al., 2016). Highly skilled workers may move from foreign to domestic firms and share their training and experience (Görg & Strobl, 2005). Domestic firms can observe and imitate the technology of nearby foreign plants (Wang and Blomstrom, 1992). The competition with foreign firms will cause domestic firms to upgrade their technologies (Blomström & Kokko, 1998). Empirical studies have found that although there are examples of positive spillover effects, domestic firms are often unable to adopt foreign practices (Singh & Zammit, 1998). When domestic firms fail to compete with foreign rivals, they are sometimes forced to operate on a smaller, less efficient scale (Aitken & Harrison, 1999).

Few of the studies on foreign influence focus on the coal power sector. Lovely and Popp (2011) estimate a model of the mechanism linking trade and clean technology adoption among coal power plants. Herrerias et al. (2013) test whether foreign investment plays a role in lowering energy intensity in China's coal consumption. Li and Gallagher (2019) and Springer et al. (2020) compare the performance of power plants based on whether or not they are owned or financed by China. There is a significant dearth of quantitative research differentiating the energy or environmental performance of coal power plants by financing source, especially in Asia, where coal continues to be at the center of energy development.

Using a dataset of 2108 coal-fired power plants, this study explores the effects of foreign investment on Asia's coal power development. We proxy foreign investment in this paper by constructing a metric of whether or not the design and engineering firm associated with each power plant was foreign-based. We do not measure foreign investment directly because such information is difficult to gather. However, large foreign investments often encourage the use of design and engineering firms from the financing country. We adapt the model specification from Springer et al. (2020), which evaluates the environmental performance of China's overseas coal plants. We make several contributions to the literature. First, we distinguish coal power plants from other industries in the manufacturing sector. This allows us to avoid heterogeneity across many industries and identify specific characteristics of coal power plants to precisely measure technological performance and spillovers (Damijan et al., 2013). Second, we examine whether the foreign country of the architecture/engineering company matters for environmental performance. This sheds light on the influence of specific foreign investment countries given their technology and internal environmental standards. Third, we decompose the emissions per unit of electricity into heat rate (coal per unit of electricity) and emission factor (emissions per unit of coal). The heat rate measures the efficiency of the technology, which one would expect the market to deliver because higher efficiency increases profitability. The emission factor is an indicator of environmental policy, which pure profitability incentives are unlikely to influence.

Our results indicate that foreign investment slightly increases the energy efficiency of coal-fired power plants in Asia. The magnitude and direction of the effect depends on the country making the investment, but the effect arises mainly from the introduction of advanced technologies. The foreign effect on clean coal choices is small and limited to two foreign countries: South Korea and the United States. The spillover effect is small and insignificant.

2. Methodology

To test whether foreign-funded coal power plants are cleaner than domestic coal power plants, we estimate the aggregate effect of a dummy for foreign investment on the performance of coal power plants with the following regression:

$$lnY_{ic} = \beta FOREIGN_{ic} + \gamma X_{ic} + \theta_c + \varepsilon_{ic} \qquad (1)$$

where Y_{ic} is the performance indicator (CO_2 emission intensity, heat rate, or emission factor) of coal power generating unit i located in country c in 2019; $FOREIGN_{ic}$ equals 1 if a generating unit i in the country c was financed by a foreign firm and 0 otherwise; X_{ic} denotes a series of control variables at the unit and country levels as well as the year of first operation; θ_c is the country fixed effect, capturing all time-invariant characteristics across countries where plants are located; and ε_{ic} is the error term. To accommodate potential heteroscedasticity, the standard errors are clustered at the country level.

The overall effect is the CO_2 emission intensity (tonnes of CO_2 per MWh of electricity). This measure examines emissions controlling for plant size. The lower the emission intensity, the cleaner the power plant. Emission intensity can be decomposed into two parts: heat rate (MBTU/MWh of electricity) (EIA, 2020b) and an emission factor (tonnes of CO_2 /MBTU) (United Nations, 2017). The heat rate or energy efficiency is a measure of technology, and it improves the profitability of the power plant. It is likely something that market competition would encourage. The emission factor is a pure environmental measure that does not necessarily increase profitability. Because these two components are influenced by different forces, we test whether foreign influence affects them the same way. We take natural logarithms of each of all three performance indicators so that they can be easily compared (the units of measurement do not matter). Note that the CO_2 emission intensity is the product of the heat rate and the emission factor; therefore, the coefficients in the heat rate regression and emission factor regression add up to those in the emission intensity regression.

$$Emission\ Intensity \equiv Heat\ Rate \times Emission\ Factor$$

In addition to equation (1), we also wish to test whether the outcome depends on the financing country. We identify which country is supporting the project in equation (2):

$$lnY_{ic} = \beta FCOUNTRY_{icx} + \gamma X_{ic} + \theta_c + \varepsilon_{ic} \tag{2}$$

We replace $FOREIGN_{ic}$ with a set of dummy variables, $FCOUNTRY_{icx}$ for each foreign country (or region): $China_{ic}$, US_{ic}, $Japan_{ic}$, $Korea_{ic}$, $Russia_{ic}$, EU_{ic} and $Other_{ic}$. The subscript x identifies the foreign country. The reference group remains the domestic power plants. The coefficient of $FCOUNTRY_{icx}$ measures the relative performance of a coal powerplant designed by country x relative to domestic power plants. Time-varying control variables and fixed effects are included as above to account for heterogeneity.

Next, we adjust the regressions to test for the existence of a spillover effect. The question here is whether domestic plants become more efficient when they are built after a foreign plant has been situated nearby (in the same region of the country). The sample is a panel of domestic plants by year of first operation. Instead of having the unit-level variable $FOREIGN_{ic}$ as the main regressor, we use a region-level dummy $FOREIGN\_PRESENCE_{ir}$ that captures the presence of foreign plants by year in each region. Regions are defined based on regional power grids for China and India and national administrative boundaries for smaller countries in Asia (see Figure A1). $FOREIGN\_PRESENCE_{ir}$ equals 1 if there was at least one foreign coal power plant in the region before the year of operation for the generating unit i. Any spillover effects from foreign to domestic plants will cause nonzero values of β. Region fixed effect θ_r controls for time-invariant characteristics in each region. Apart from the control variables in specification (1), we also add domestic plant capacity to account for the impact of plant size on heat rate. This variable is not included in specification (1) and (2) due to the potential endogeneity of plant size in foreign investment decisions. The endogeneity concern does not hold for specification (3) and (4) since we assume $FOREIGN\_PRESENCE_{ir}$ does not affect the size of domestic power plants and local electricity demand.

$$lnY_{ir} = \beta FOREIGN\_PRESENCE_{ir} + \gamma X_{ic} + \theta_r + \varepsilon_{ir} \tag{3}$$

As with specification (2), we test whether it matters which foreign country is supporting power plants in equation (4) by replacing $FCOUNTRY$ with $FCOUNTRY\_PRESENCE_{irx}$. This variable equals 1 if there has been at least one foreign-funded power plant from country x in the region before the year of operation for the generating unit i. The rest of the variables incorporated in (4) are the same as those in (3).

$$lnY_{ir} = \beta FCOUNTRY\_PRESENCE_{irx} + \gamma X_{ic} + \theta_r + \varepsilon_{ir} \tag{4}$$

3. Data

The coal power data for this study come from two main sources: the Platts World Electric Power Plants (WEPP) Database and the Global Coal Plant Tracker (GCPT). WEPP is a global inventory of electric power generating units that covers 95% of coal-fired facilities over 100MW worldwide (S&P Global, 2020). Its Q4 2019 version includes 9244 coal-fired units in Asia and contains complete information on capacity, operation year, status and ownership. WEPP is used as the master dataset in this research. The Global Coal Plant Tracker, published by Global Energy Monitor, is another unit-level inventory of existing and proposed coal plants (Tracker, 2020). It links to a Wiki page on SourceWatch for each coal power plant and is a good source for data validation. Key variables such as CO_2 emission intensity are acquired from this source.

We collect a rich set of time-varying controls from various sources. Plant-level controls come from WEPP, including electricity production types (utility, commercial or private) and company business types (services, manufacturing, fuels, etc.). Country-level controls include economic, political, and resource factors, among which GDP per capita and population density are from the World Bank Development Indicators (World Bank, 2020), economic risks and political stability metrics come from the International Country Risk Guide (PRS Group, 2020), and coal reserves are acquired from the U.S. Energy Information Administration (EIA, 2020a).

It is worth noting that CO_2 emission intensity data in this study are estimated rather than observed. There are several sources on observed or modeled power plant emissions, such as the Global Power Emissions Database (GPED) (Tong et al., 2018), Open-Data Inventory for Anthropogenic Carbon dioxide (ODIAC) (Oda & Maksyutov, 2015) and Carbon Monitoring for Action (CARMA) (Ummel, 2012). However, GPED and CARMA, on the plant level, ignore the vast heterogeneity among generating units in each plant. ODIAC only has aggregate fossil fuel emissions, making it difficult to determine individual power plant emissions. Additional modeled data on plant-level emissions, such as Oberschelp et al. (2019) and Steinmann et al. (2014), lacks ownership characteristics and covers a smaller subset of global coal-fired power plants. To the best of our knowledge, GCPT provides the most comprehensive and up-to-date coverage of coal plants with heat rate and emissions factor data.

To check whether engineering estimates from GCPT lead to noisy and biased results, we validate the emission data by aggregating unit-level emissions to the plant level and merging them with the data from GPED. The results are shown in Figure A2. Based on 530 plants that are successfully matched, the GCPT estimates appear to be precise and unbiased. Since GCPT clearly lays out its methodology on the website and updates values each year, we use it as the main source for CO_2 emission intensity.

Another data challenge is linking finance or investment sources to individual power plants. Given the sensitive nature of pollution from coal-fired power plants, countries provide very limited public disclosure of their overseas coal power projects (Bast et al., 2015). In addition, financing arrangements for large infrastructure projects like coal-fired power plants may be complicated involving multiple institutions and tranches of finance over time. In the absence of detailed information on investment amounts, we use the country of origin of the architect/engineering companies (AE companies) as a proxy for ownership, as these companies play an essential role in determining the architectural design and technological choices for power plants. For foreign AE companies operating in a host country, there is frequently, if not always, associated finance from an institution in the AE company's home country. We consult the WEPP data on AE companies, identify their countries of origin based on data from Springer et al. (2021), and code them with a dummy treatment variable of domestic or foreign ownership. We use the information about foreign country to test whether the specific country matters for environmental performance.

4. Results

4.1. Summary statistics

Table 1 shows the means, standard deviations, and data availability for the main variables in our analysis. Of the 5413 coal-fired units in operation in Asia, AE company data are available for 2677 observations, of which 2199 have information on CO_2 emission intensity. Relatively speaking, domestic power plants are larger in scale, built later, and mainly used for utility services. There does not seem to be a significant difference between the CO_2 emission intensity of domestic and foreign power plants, though the former are slightly cleaner on average, which may result from the fact that they are generally newer. At the country level, foreign architect and engineering companies mainly work with poorer countries, which are characterized by lower GDP per capita, denser population and higher economic and political risks. Resource abundance is also taken into consideration in investment decisions, in that plants with foreign stakeholders tend to locate in countries with larger coal reserves per capita.

Table 1 Summary statistics by AE company ownership

	Domestic		Foreign	
	Observations	Mean (S.D.)	Observations	Mean (S.D.)
CO_2 Emission Intensity (tCO_2/MWh)	1667	1.03 (0.13)	532	1.07 (0.14)
Year of First Operation	2017	2006 (8.6)	633	2003 (13.3)
Capacity (MW)	1684	399 (259)	545	304 (245)
Electric Production Type				
Autoproducer, Commercial or Industrial	360	17.6%	104	16.4%
Utility	1327	64.9%	285	45.0%
Private	356	17.4%	245	38.6%
Company Business Type				

Commercial	41	2.0%	9	1.4%
Fuels	68	3.3%	22	3.5%
Manufacturing	337	16.5%	103	16.3%
Services	259	12.7%	217	34.2%
Utility	1336	65.4%	283	44.6%
Others	2	0.1%	0	0.00%
Country-level Indicators				
GDP Per Capita (2010 US$)	2017	4301 (6033)	589	2874 (4344)
Population Density (people per sq. km)	2013	229 (145)	633	265 (451)
Economic Risk (0-100, higher rating means lower risk)	1989	38.0 (3.3)	566	35.3 (4.1)
Political Stability (0-100, higher rating means lower risk)	1989	63.8 (6.4)	566	60.7 (7.31)
Coal Reserves Per Capita (short tons)	2017	89.7 (44.0)	633	95.0 (256.6)

Table 2 summarizes the characteristics of plants with AE companies from different countries. Despite the fact that most plants in the dataset are domestic, China, the U.S., Japan and the EU have invested in a number of plants overseas. The EU, Russia, and the U.S. built overseas coal plants largely in the 20th century, while Chinese and South Korean plants are more recent. The average emission intensity varies across countries, from 0.92 tCO_2/MWh for South Korean plants to 1.23 tCO_2/MWh for Russia. In light of the timeline of these investments, we include the year of first operation in the model to absorb the time-varying factors such as technological advancement.

Table 2 Summary statistics by country of the AE company†

Financing Country/Region	Observations	Year Built	Capacity (MW)	Emission Intensity (tCO_2/MWh)
Home Country	1638	2007 (8.0)	405 (256)	1.03 (0.13)
China	251	2012 (5.1)	295 (229)	1.02 (0.11)
US	72	1999 (5.3)	390 (228)	1.11 (0.09)
Japan	39	2002 (12.2)	426 (258)	1.08 (0.16)
Korea	21	2016 (2.8)	510 (295)	0.92 (0.10)

† Note that this table is conditional on non-missing data on all variables in the model in order to reflect observations included in the regression.

Russia	12	1993 (4.4)	322 (261)	1.23 (0.11)
EU	40	1996 (6.6)	413 (245)	1.11 (0.10)
Other	35	2008 (9.1)	186 (205)	1.09 (0.10)
Total	2,108	2007 (8.3)	389 (255)	1.03 (0.13)

Investigating further into the cross-country difference, Figure A3 depicts the interquartile ranges of emission intensities by financing country. Without controlling for other factors, South Korean-owned plants are more efficient than domestic plants, but other foreign plants are not.

4.2. Are foreign-financed plants cleaner or dirtier than their domestic counterparts?

Table 3 reports the estimates from equation (1). Columns 1-3 show the results for the logarithm of emission intensity, heat rate and emission factor, respectively, with both fixed effects and controls included. Overall, the results indicate a significant but small reduction (3.4%, or 0.036 tCO_2/MWh) in CO_2 emission intensity resulting from foreign investment. This is confirmation that there is a small Pollution Halo effect. The F-statistics for fixed effects and controls are 59.1 and 49.7, respectively, suggesting that these controls also have a significant effect on outcomes.

Columns 2 and 3 separate out the effects of heat rate and emission factor. As components, the coefficients of heat rate and emission factor add up to the coefficient of emission intensity. Almost all the effect of foreign investment (96%) lies in the reduction in heat rates (3.3%) compared to emission factors (0.1%). The emissions are lower in these foreign plants primarily because of better technology that increases energy efficiency rather than an explicit effort to lower emissions.

Table 3 The effect of foreign investment on performance of coal power plants

VARIABLES	(1) logEMISINT	(2) logHEATRATE	(3) logEMISFAC
FOREIGN	-3.430*** (0.597)	-3.303*** (0.557)	-0.127 (0.073)

Observations	2,108	2,108	2,108
R-squared	0.658	0.681	0.113
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Controls	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY
r2_a	0.648	0.671	0.086

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

To further explore this Pollution Halo effect, we separate out the country that owns the AE company in Table 4 using equation (2). Columns 1-3 show the results for the logarithm of emission intensity, heat rate and emission factor, respectively, with both fixed effects and controls included. For the first column, all the estimates except for Russia are negative, meaning that most foreign countries contribute to the Pollution Halo in Asia. South Korea has the largest helpful effect of 9%, while the United States and the European Union effects are about 6% and Japan effects are 5%. China has built the most plants in Asia (outside China), but these plants do not perform better than domestic plants.

In terms of drivers, most of the positive effects of foreign investment from the United States, the European Union, Japan and South Korea come from improvements in heat rate. Only the plants built by the United States (0.44%) and South Korea (0.99%) slightly help by using cleaner coal. These results suggest that it is the technology upgrades from these countries that are causing better environmental performance.

Table 4 The effect of foreign investment on power plants performance by financing country

VARIABLES	(1) logEMISINT	(2) logHEATRATE	(3) logEMISFAC
CHINA	-2.290	-2.162	-0.128
	(1.526)	(1.371)	(0.176)
US	-6.040***	-5.596***	-0.443**
	(1.514)	(1.395)	(0.170)
JAPAN	-4.969**	-5.062**	0.093
	(2.263)	(1.961)	(0.692)
KOREA	-8.934***	-7.943***	-0.992***
	(2.128)	(2.005)	(0.188)

RUSSIA	1.991	1.020	0.972
	(3.813)	(3.124)	(0.705)
EU	-6.155***	-6.092***	-0.063
	(1.509)	(1.426)	(0.166)
OTHER	-2.511	-2.764	0.253
	(2.160)	(1.759)	(0.488)
Observations	2,108	2,108	2,108
R-squared	0.664	0.685	0.120
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Controls	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY
r2_a	0.652	0.675	0.0902

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

4.3. Are there spillover effects?

This section tests whether there is any evidence of spillovers from foreign to domestic plants using equation (3). Columns 1-3 in Table 5 refer to estimates for the dependent variables: emission rate, heat rate, and the emission factor, respectively. Overall, there is no spillover effect for CO_2 emission intensity. However, the positive spillover effect for heat rate is not significant, suggesting that subsequent domestic plants are not affected by the presence of a foreign plant nearby. The emission factor actually increases (a negative spillover) if a foreign plant is nearby. One possible explanation is that the foreign plant tends to tap the only nearby source of clean coal leaving only dirty sources for the domestic plant. The magnitude of the spillover coefficients is much smaller than the gap between foreign and domestic firms. It appears to be difficult for domestic firms to acquire the coal technology of foreign firms even after a foreign plant is built nearby.

Table 5 The spillover effect of foreign investment on domestic power plants

VARIABLES	(1) logEMISINT	(2) logHEATRATE	(3) logEMISFAC
FOREIGN_PRESENCE	-0.351	-0.788	0.437**
	(0.572)	(0.486)	(0.140)
Observations	1,638	1,638	1,638

R-squared	0.904	0.915	0.149
Region FE	YES	YES	YES
Year FE	YES	YES	YES
Controls	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY
r2_a	0.900	0.911	0.113

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

More subtle insights are gained by running regression (4), where foreign ownership is further classified by country. As is shown in Table 6, the signs and magnitude of coefficients vary across financing countries. Russia is the only country that has both a negative spillover from heat rate and a negative spillover from the emission factor. Regression (2) suggests that Russian power plants are dirtier than Asia's domestic plants. Subsequently built domestic plants tend to be negatively impacted by the Russian example in the same region. Additionally, the Russian plants are mainly located in Western India and Northeastern China, which are traditional industrial bases with high emissions.

Only China (2.1%) and Japan (3.9%) have significant positive spillover effects on emissions. There are no measurable spillovers for South Korea, the United States, or the European Union. For China, the spillover benefit mainly comes from better heat rates. For Japan, 41% of the spillover is from improved heat rates and 59% from lower emission factors. The United States contributes to a small heat rate spillover. However, this is offset by a negative spillover from the emission factor which explains why there is no overall emission spillover from the United States coal plants.

The magnitude of the spillover effects for China is similar to the difference between the Chinese-funded plants and domestically funded plants. In contrast, the spillover effect for every other foreign country except Japan is much smaller. This suggests that Chinese technology may be easier for host countries to copy. It is not clear whether this is a technological issue or caused by other factors such as intellectual property protection.

Table 6 The spillover effect of foreign investment on domestic power plants by financing country

	(1)	(2)	(3)

VARIABLES	logEMISINT	logHEATRATE	logEMISFAC
CHINA_PRESENCE	-2.101**	-1.715**	-0.386**
	(0.655)	(0.591)	(0.130)
US_PRESENCE	0.104	-0.734	0.838***
	(0.611)	(0.453)	(0.161)
JAPAN_PRESENCE	-3.901***	-1.600	-2.301***
	(0.553)	(0.930)	(0.392)
KOREA_PRESENCE	0.364	0.220	0.143
	(0.629)	(0.580)	(0.113)
RUSSIA_PRESENCE	2.437***	0.731	1.706***
	(0.173)	(0.395)	(0.298)
EU_PRESENCE	0.178	0.131	0.047
	(0.117)	(0.140)	(0.050)
OTHER_PRESENCE	0.264	0.658**	-0.394*
	(0.262)	(0.262)	(0.203)
Observations	1,638	1,638	1,638
R-squared	0.905	0.915	0.158
Region FE	YES	YES	YES
Year FE	YES	YES	YES
Controls	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY
r2_a	0.900	0.911	0.119

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

These findings are consistent with the existing literature. Schoors and Van Der Tol (2002) find that spillover effects within sectors are less important than spillovers between sectors. Damijan et al. (2013) suggest that foreign investors may do a good job preventing their patents and specialized knowledge from being shared by local firms. The difficulty of duplicating the technology of sophisticated power plants may well be a barrier to the spread of efficient technologies across power plants.

5. Robustness Checks

5.2. Impact of country-level control variables

In the previous analysis, we employed a dataset of coal power plants in Asia that started operation between 1984 and 2019. There were another 373 power plants in operation before 1984, which were dropped from the regressions due to the unavailability of some country-level control variables. To investigate whether missing data biased the results, we extend the sample size in the regressions by removing some of the country-level controls.

In the first set of robustness checks (columns 1-3 of Table A1 to Table A4), we remove the economic and political risk metrics. These variables are only available since 1984 and therefore are the main source of sample restrictions. The second set of robustness checks (columns 4-6 of Table A1 to Table A4) is focused on the regressions without risks and coal reserves, the latter of which was originally available intermittently and were interpolated in the years in between. Other relatively complete controls, including GDP per capita, population density, and plant-level electricity type and business type, are kept in the regressions to reduce omitted variable bias. The data is expanded back to 1965 and 41 observations are added to the analysis.

Results for the first hypothesis are presented in Table A1 and Table A2. Most estimates are quite robust and consistent. The overall improvement made by foreign power plants is around 3.5%. Among the main foreign financiers, South Korean power plants are the cleanest, followed by other developed countries such as the U.S., Japan and EU. In terms of spillover effects, a significant but minimal technology spillover effect is observed, but it is offset by the negative coal source spillover effects (Table A3 and Table A4). Japan and China make the most contribution to reducing emissions intensity of domestic plants, and Russia drives up local emissions intensity, as was observed in Table 5 and Table 6. Therefore, our estimation appears to be robust, suggesting that foreign plants generally have better heat rates than domestic plants and that there is very little evidence of spillover effects from foreign to nearby domestic plants in Asia.

5.2 Lags in spillover effects

The spillover analysis in the last section tested whether having a foreign plant improved the performance of domestic plants built afterward. We used a one-year lag, assuming that modern technologies could become accessible to domestic plants as soon as foreign plants enter the region. This may not be the case when there are information frictions preventing domestic plants from learning about efficient practices. It is also possible that it takes time for power plants to build up connections and learn from one another. We test these possibilities by adding three-year and five-year lags to the main regressor $PRESENCE_{ir}$ in specifications (3) and (4). The results are shown in Table A5 in the Appendix. The estimates with both lags are very small in magnitude, supporting the claim that spillover effects are not observed in Asia.

More insights can be drawn from Table A6, where financing countries are separated. It is found that spillover effects of China diminish fairly quickly in the years following the introduction of Chinese plants, while Japan brings long-lasting positive spillovers. The U.S. and the EU bring significantly negative spillover effects, in contrast to their insignificant impacts in Table 6. This implies that the positive technology spillovers fade away within three years after foreign power plants come into a region. Once we filter out the immediate domestic plants built within three/five years, we cannot observe positive spillover effects for most financing countries. Adding longer lags does not lead to additional effects.

6. Conclusion

This paper examines how foreign investors affect the environmental performance of coal-fired power plants in Asia. Using countries of origin for architect and engineering (AE) companies as a proxy for the sources of foreign investment, we tested whether foreign coal plants are more efficient and have lower emissions than domestic coal plants. We also tested whether there are spillover effects from foreign coal plants to their domestic counterparts. The results show that plants with foreign AE companies are significantly cleaner than their domestic counterparts, but the difference is relatively small (3.43%). South Korea has the cleanest overseas coal power plants, with 8.9% lower CO_2 emission intensity than the domestically funded counterparts. The United States, Japan, and the European Union also have cleaner power plants with 5-6% lower emission intensity. The emission intensity of coal plants from China, which has built the most coal plants in Asia, is the same as the emission intensity of domestic power plants. Russian-funded plants are even dirtier than domestic plants. Coal plants funded by emerging countries, such as China and Russia, have no significantly better environmental performance than domestic plants in Asia.

The primary mechanism driving lower emission rates in foreign coal plants is better heat rates. By burning less fuel per amount of electricity generated, these plants have lower CO_2 emission intensity. The technology explains 96% of the emission reduction. Only the coal plants built by the United States and South Korea tended to use cleaner coal as well.

We are able to observe only a very limited spillover effect from foreign to domestic plants. Domestic coal plants get very little spillover gains when foreign plants are built. We hypothesize that the complexity of coal plant technologies and the protection against intellectual property diffusion make imitating modern foreign plants difficult.

Several directions for future research should be noted. First, we do not have access to time-series monitored CO_2 emission data. When such data become available, researchers can conduct dynamic analyses capturing emissions over time. Second, this study uses the home country of the firm that designed and built the coal plant, one form of foreign involvement. Regressions with more comprehensive measures, from financing and ownership to design, construction, and operation, might reveal richer dynamics between foreign stakeholders and domestic firms. Third, future research may consider emissions of sulfur dioxide, particulates, and nitrogen oxides, which would provide a more comprehensive view of the environmental effects of each power plant. Abatement technology may have a large effect on these emissions, and this technology can vary a great deal across power plants, but such data is not currently available at the plant level. Finally, a very important macro question remains unaddressed: how much has foreign investment and involvement increased the total number of coal power plants built in Asia? If the world is going to reduce its reliance on coal in order to protect the climate, countries need to cooperate on reducing coal plants everywhere.

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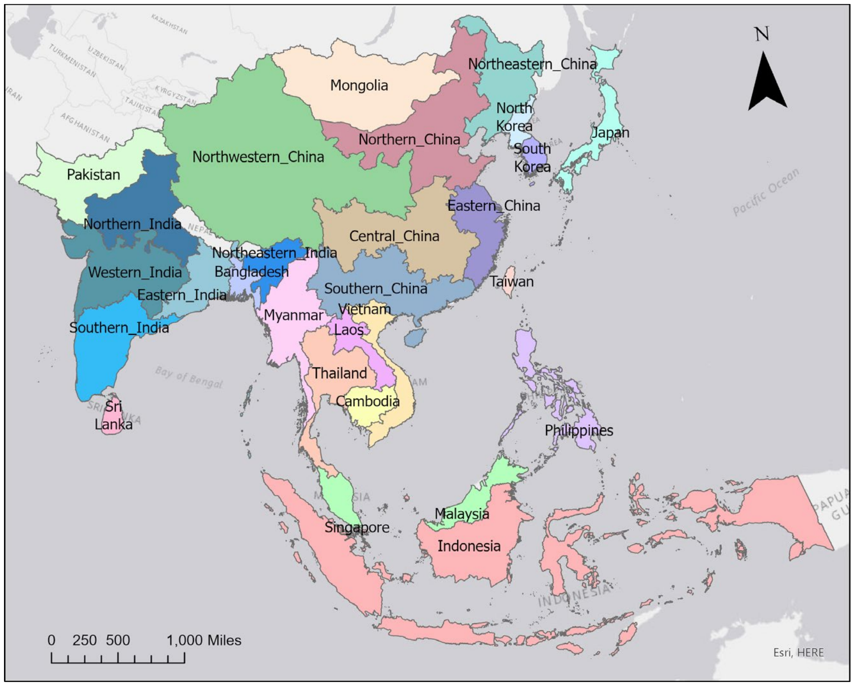
Online Appendix

Figure A1 Definition of regions in Asia in this study



Note: The map is made by the authors using data from *Global Administrative Boundaries*. (2018). GADM. https://gadm.org/download_country_v3.html

Figure A2 Comparison between GCPT and GPED emission data

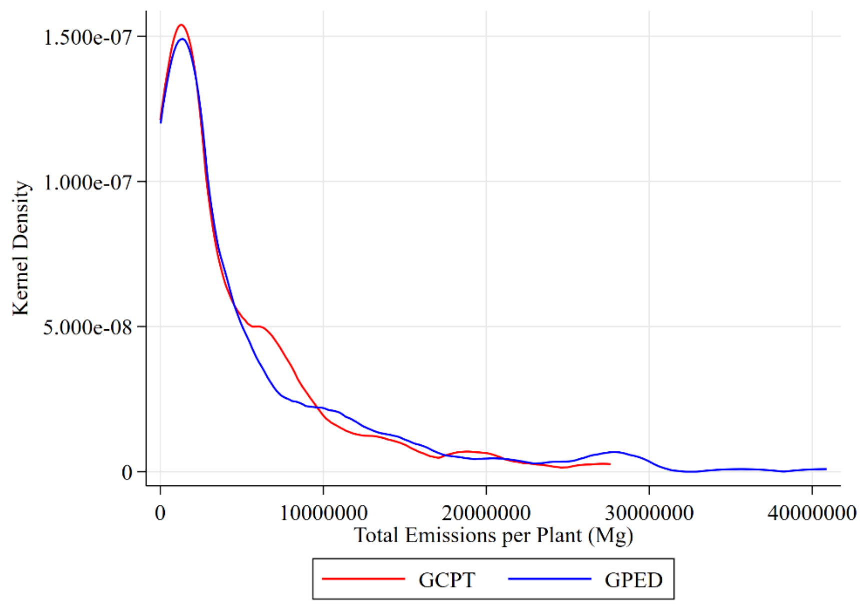


Figure A3 CO_2 emission intensity by financing country

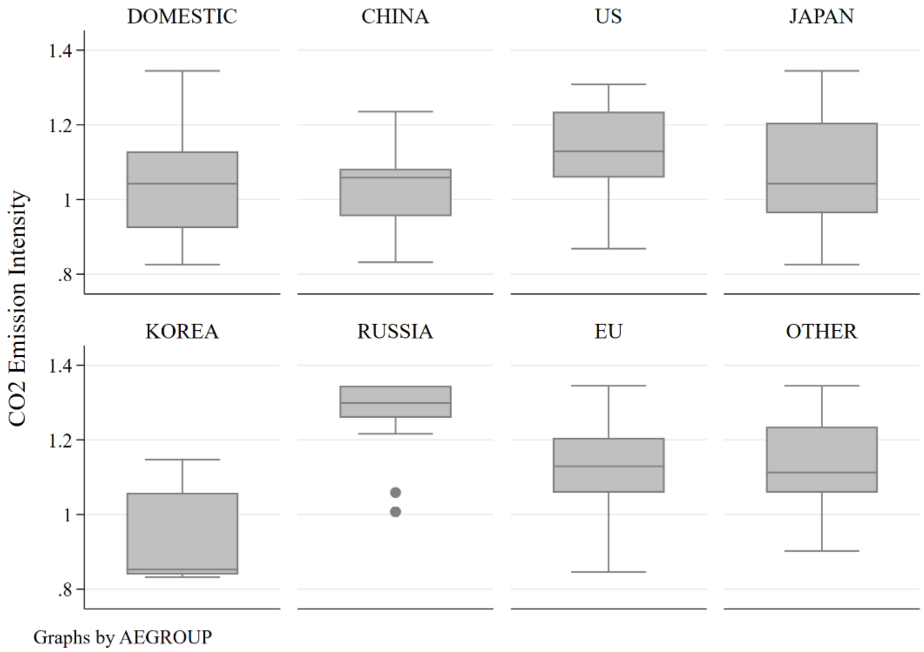


Table A1 The effect of foreign investment on full-sample coal power plants

VARIABLES	(1) logEMISINT (w/o risks)	(2) logHEATRATE (w/o risks)	(3) logEMISFAC (w/o risks)	(4) logEMISINT (w/o risks/coal)	(5) logHEATRATE (w/o risks/coal)	(6) logEMISFAC (w/o risks/coal)
FOREIGN	-3.467***	-3.306***	-0.161**	-3.704***	-3.552***	-0.152**
	(0.595)	(0.565)	(0.059)	(0.499)	(0.481)	(0.063)
Observations	2,149	2,149	2,149	2,149	2,149	2,149
R-squared	0.671	0.694	0.127	0.664	0.686	0.126
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.660	0.683	0.0967	0.652	0.675	0.0965

Robust standard errors in parentheses

Coefficients and standard errors are multiplied by 100 for readability

*** p<0.01, ** p<0.05, * p<0.1

Note: For this set of regressions and the following regressions alike, the coefficients of control variables (not reported in the text) largely make sense. The coefficient for GDP per capita is negative, and that for GDP per capita squared is positive. These are in line with the Environmental Kuznets Curve which predicts an inverted "U" shape curve between pollution and economic growth. The coefficient of population density is positive, indicating that the denser the population, the less developed the region likely is, and the more pollution power plants are expected to produce. Economic risk has a negative coefficient, meaning that stabler regions have relatively stronger regulations and cleaner power plants. Political risk has a slightly positive but insignificant coefficient. The coefficient of coal reserve per capita is positive, implying that countries with rich coal resources on average have dirtier power plants than those that need to import coal from overseas.

Table A2 The effect of foreign investment on full-sample coal power plants by financing country

VARIABLES	(1) logEMISINT (w/o risks)	(2) logHEATRATE (w/o risks)	(3) logEMISFAC (w/o risks)	(4) logEMISINT (w/o risks/coal)	(5) logHEATRATE (w/o risks/coal)	(6) logEMISFAC (w/o risks/coal)
CHINA	-2.269	-2.127	-0.142	-2.005	-1.847	-0.158
	(1.497)	(1.344)	(0.178)	(1.646)	(1.492)	(0.173)
US	-5.871***	-5.330***	-0.541***	-6.872***	-6.389***	-0.483***
	(1.328)	(1.211)	(0.165)	(2.032)	(1.972)	(0.147)
JAPAN	-5.260**	-5.339**	0.079	-6.454**	-6.601**	0.148
	(2.250)	(1.935)	(0.711)	(2.645)	(2.380)	(0.716)
KOREA	-9.005***	-7.975***	-1.030***	-9.205***	-8.186***	-1.019***
	(2.178)	(2.107)	(0.153)	(2.266)	(2.202)	(0.152)
RUSSIA	2.036	1.007	1.029	2.742	1.754	0.989
	(3.934)	(3.252)	(0.696)	(3.774)	(3.116)	(0.702)
EU	-6.280***	-6.101***	-0.179	-6.997***	-6.860***	-0.138
	(1.369)	(1.284)	(0.145)	(1.702)	(1.636)	(0.146)
OTHER	-2.582	-2.882	0.300	-3.367*	-3.712**	0.345
	(2.053)	(1.663)	(0.504)	(1.918)	(1.504)	(0.498)
Observations	2,149	2,149	2,149	2,149	2,149	2,149
R-squared	0.676	0.698	0.134	0.672	0.693	0.133
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.664	0.687	0.102	0.660	0.682	0.102

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

Table A3 The spillover effect on full-sample coal power plants

VARIABLES	(1) logEMISINT (w/o risks)	(2) logHEATRATE (w/o risks)	(3) logEMISFAC (w/o risks)	(4) logEMISINT (w/o risks/coal)	(5) logHEATRATE (w/o risks/coal)	(6) logEMISFAC (w/o risks/coal)
FOREIGN_PRESENCE	-0.527	-0.910*	0.383**	-0.813**	-1.146***	0.333***
	(0.494)	(0.423)	(0.117)	(0.242)	(0.206)	(0.086)
Observations	1,650	1,650	1,650	1,650	1,650	1,650
R-squared	0.906	0.916	0.153	0.904	0.914	0.149
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.902	0.912	0.117	0.900	0.911	0.114

Robust standard errors in parentheses

Coefficients and standard errors are multiplied by 100 for readability

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4 The spillover effect on full-sample coal power plants by financing country

VARIABLES	(1) logEMISINT (w/o risks)	(2) logHEATRATE (w/o risks)	(3) logEMISFAC (w/o risks)	(4) logEMISINT (w/o risks/coal)	(5) logHEATRATE (w/o risks/coal)	(6) logEMISFAC (w/o risks/coal)
CHINA_PRESENCE	-1.914**	-1.560**	-0.354**	-1.195	-0.981	-0.214***
	(0.599)	(0.604)	(0.102)	(0.961)	(0.925)	(0.054)
US_PRESENCE	0.128	-0.594	0.722***	-0.092	-0.771*	0.679***
	(0.593)	(0.599)	(0.049)	(0.328)	(0.383)	(0.084)
JAPAN_PRESENCE	-2.784***	-0.990	-1.794***	-3.559***	-1.615*	-1.944***
	(0.645)	(0.995)	(0.363)	(0.457)	(0.843)	(0.430)
KOREA_PRESENCE	0.883	0.793	0.090	0.832	0.752	0.080
	(0.682)	(0.677)	(0.310)	(0.791)	(0.888)	(0.222)
RUSSIA_PRESENCE	1.308*	0.101	1.207***	2.406***	0.985	1.421***
	(0.553)	(0.697)	(0.187)	(0.490)	(0.578)	(0.313)
EU_PRESENCE	0.011	-0.025	0.037	0.323*	0.225	0.097
	(0.184)	(0.228)	(0.078)	(0.170)	(0.193)	(0.109)
OTHER_PRESENCE	0.680	1.162*	-0.482*	1.715**	1.995***	-0.281
	(0.388)	(0.510)	(0.236)	(0.537)	(0.539)	(0.230)
Observations	1,650	1,650	1,650	1,650	1,650	1,650
R-squared	0.906	0.916	0.160	0.904	0.915	0.156
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.902	0.912	0.122	0.900	0.911	0.118

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** p<0.01, ** p<0.05, * p<0.1

Table A5 The spillover effect with lags of foreign presence

VARIABLES	(1) logEMISINT (3-year lag)	(2) logHEATRATE (3-year lag)	(3) logEMISFAC (3-year lag)	(4) logEMISINT (5-year lag)	(5) logHEATRATE (5-year lag)	(6) logEMISFAC (5-year lag)
FOREIGN_PRESENCE	0.034**	0.034*	0.000	0.064***	0.064***	-0.000
	(0.014)	(0.017)	(0.007)	(0.016)	(0.013)	(0.010)
Observations	1,638	1,638	1,638	1,638	1,638	1,638
R-squared	0.904	0.915	0.147	0.904	0.915	0.147
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.900	0.911	0.112	0.900	0.911	0.112

Robust standard errors in parentheses

Coefficients and standard errors are multiplied by 100 for readability

*** p<0.01, ** p<0.05, * p<0.1

Table A6 The spillover effect with lags of foreign presence by financing country

VARIABLES	(1) logEMISINT (3-year lag)	(2) logHEATRATE (3-year lag)	(3) logEMISFAC (3-year lag)	(4) logEMISINT (5-year lag)	(5) logHEATRATE (5-year lag)	(6) logEMISFAC (5-year lag)
CHINA_PRESENCE	0.003	0.000	0.003	0.040	0.039*	0.002
	(0.025)	(0.025)	(0.005)	(0.022)	(0.019)	(0.006)
US_PRESENCE	0.198**	0.212***	-0.013	0.171	0.182*	-0.011
	(0.072)	(0.056)	(0.017)	(0.096)	(0.082)	(0.015)
JAPAN_PRESENCE	-1.927***	-1.845***	-0.082	-1.494**	-1.544**	0.050
	(0.240)	(0.259)	(0.055)	(0.548)	(0.473)	(0.082)
KOREA_PRESENCE	0.296	0.271	0.025	-0.230	-0.063	-0.167
	(0.560)	(0.671)	(0.122)	(2.197)	(2.339)	(0.276)
RUSSIA_PRESENCE	0.560***	0.520***	0.041	0.418***	0.387***	0.031
	(0.096)	(0.058)	(0.083)	(0.082)	(0.077)	(0.041)
EU_PRESENCE	0.114**	0.111**	0.003	0.097*	0.105*	-0.009
	(0.045)	(0.039)	(0.009)	(0.050)	(0.053)	(0.005)
OTHER_PRESENCE	-0.058	-0.060	0.002	-0.015	-0.057	0.042
	(0.108)	(0.071)	(0.053)	(0.135)	(0.153)	(0.024)
Observations	1,638	1,638	1,638	1,638	1,638	1,638
R-squared	0.905	0.916	0.148	0.905	0.916	0.148
Country FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES
Cluster	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY	COUNTRY
r2_a	0.901	0.912	0.108	0.901	0.912	0.109

Robust standard errors in parentheses
Coefficients and standard errors are multiplied by 100 for readability
*** $p<0.01$, ** $p<0.05$, * $p<0.1$