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Environmental regulation and foreign direct investment: Evidence from South Korea☆

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ABSTRACT

This paper studies how environmental regulation shapes the pattern of foreign direct investment (FDI), and thereby assesses the pollution haven hypothesis. Conflicting results exist in the case studies examining the most advanced countries, partly due to the deterrent effect of clean technology adoptions on industry migration. To minimize the clean technology effect, we examine the pattern of South Korean FDI over 2000–2007, the period that Korean firms relied on old production technologies despite facing rapidly strengthened environmental standards. A difference-in-differences type identification strategy circumvents other potential confounders. We find strong evidence that polluting industries tend to invest more in countries with laxer environmental regulations in terms of both the amount of investment (intensive margin) and the number of new foreign affiliates (extensive margin). A similar finding is obtained when imports are analyzed.

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1. Introduction

The fall of global economic barriers, along with technological advances, has accelerated the international fragmentation of production processes. Firms strategically relocate their production systems to foreign countries where they can benefit from country-specific advantages. This incentive is referred to as the comparative advantage (or vertical) motive for foreign direct investment (FDI). An emerging question is which country-specific characteristics generate a comparative advantage that shapes the pattern of FDI. The literature has typically focused on factor endowments, such as skilled labor and physical capital, and found evidence that countries with an abundant factor endowment attract more foreign investors in industries that use the given factor intensively (e.g., Antràs, 2003; Yeaple, 2003).

Interestingly, in a separate strand of literature, the laxity of environmental regulations has also been assessed as a potential source of comparative advantage. The theoretical rationale is straightforward: polluting firms have an incentive to shift their production system to countries with lax environmental regulations to lower production costs. Classical Heckscher–Ohlin trade theory is then applied to predict that environmentally lax countries specialize in industries producing polluting goods, whereas environmentally stringent countries specialize in industries producing clean goods.[2] Unlike the factor endowments case, however, tests of this so-called pollution haven hypothesis (or pollution haven effect) have yielded rather conflicting and weak empirical evidence. Brunnermeier and Levinson (2004) summarize in their review that early literature up to the 1990s typically find no significant pollution haven effect, while later studies tend to find a statistically significant, but economically mild, effect of environmental regulations on industry composition.

One concern in the pollution haven literature is that it has heavily relied on empirical results from the most advanced countries, such as the U.S. (Eskeland and Harrison, 2003; Grossman and Krueger, 1994; Hanna, 2010), Germany (Wagner and Timmins, 2009), and the U.K. (Manderson and Kneller, 2012). Although these countries impose the toughest environmental standards, they also retain potential confounding factors that may dampen the pollution haven effect. A typical approach to solve the problem is to use exclusion restrictions (Kellenberg, 2009; Levinson and Taylor, 2008; Xing and Kolstad, 2002). However, the validity of exclusion restrictions is in fact often

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[2] See Pethig (1976), Copeland and Taylor (2003) for theoretical background.

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criticized (Broner et al., 2012; Millimet and Roy, 2011). Another group of studies tries directly to disentangle such confounders. Antweiler et al. (2001) and Cole and Elliott (2005), for example, posit that polluting industries, which tend to be capital intensive, may locate in advanced countries to exploit rich capital stocks despite the countries' stringent environmental regulations. Both studies find statistically significant pollution haven effects when this capital-seeking incentive is sorted out. In other studies, Ederington et al. (2005) and Wagner and Timmins (2009) argue that positive spillovers from industry agglomeration can be an important reason for polluting firms not to leave advanced countries.

Another crucial, yet overlooked, confounder is clean technology adoption. Environmental regulations may not only induce shift of production location, but also promote innovation and adoption of clean technologies (Popp et al., 2010). Firms employing clean technologies in response to the domestic environmental regulations, usually observed in the rich world, would have less incentive for outward migration.[3] In this spirit, Dean et al. (2009) examine the pattern of FDI inflows across Chinese provinces to test whether foreign firms embodying less efficient abatement technologies are more responsive to interprovincial differences of environmental regulations. Their finding confirms that only ethnically Chinese investors were significantly sensitive to the provincial differences, while non-ethnically Chinese investors who transferred relatively advanced technologies showed no significant response. Until now, studies examining the most advanced countries have failed to address this clean technology issue.

This paper provides new evidence for the pollution haven hypothesis by investigating the pattern of South Korean FDI outflows to 50 host countries in 121 industries over the period 2000–2007. The Korean case is an advantageous setting for the clean technology issue. After experiencing severe environmental degradation accompanied by dramatic economic growth, South Korea newly adopted and amended almost its entire body of environmental legislation throughout the 1990s (OECD, 1997). However, the adoption of clean technologies lags behind the change in regulations, as Korean firms, mostly small- and medium-sized ones, still rely on old, dirty production technologies. In the subsequent review, OECD (2006, p. 1) stresses that "indicators of carbon, energy and some material intensities still remain among the highest in the OECD."[4] Facing increasingly stringent environmental standards with limited access to clean technologies, the incentive for Korean firms to seek a pollution haven appears clearer than those in the most advanced countries.

To deal with other potential confounders, we employ a difference-in-differences (DID) type identification strategy, i.e., determinants of comparative advantage are identified by interaction terms between country and industry characteristics.[5] If environmental laxity is a determinant of comparative advantage, the pollution haven effect is identified through the interaction term between a host country's environmental laxity (relative to home country) and industry's pollution intensity. This approach enables us to disentangle opposing forces between environmental laxity and other determinants of comparative advantage. Furthermore, since our variables of interest are in interaction terms, we can control for all country- and industry-specific unobserved heterogeneity, in which case our model for FDI flow resembles the empirical model for trade flow used in Romalis (2004). Hence, we can apply the same model to trade data to see if a consistent behavior is observed in the pattern of trade.

After relevant issues are carefully treated, we find strong evidence for the pollution haven hypothesis. Countries with relatively lenient environmental regulations tend to attract more South Korean FDI in polluting industries than in non-polluting industries in terms of the total amount of investment (i.e., intensive margin of FDI). Economic significance is comparable to the disproportional effects of physical capital and skill endowment. This finding is robust to the inclusion of additional sources of comparative advantage. Note that, however, the same finding disappears in such cases when (i) industries are observed at a more aggregated level, (ii) physical capital is not included as a source of comparative advantage, or (iii) unobserved heterogeneity is not adequately controlled for. This highlights the importance of an elaborate identification strategy and a fairly disaggregated data. With the same identification strategy and data, we also find that the pollution haven effect is consistently observed in the patterns of new birth of foreign affiliates (i.e., extensive margins of FDI). Polluting industries show a disproportionally higher tendency to establish their new foreign affiliates in environmentally laxer countries than non-polluting industries do. When our model is applied to South Korean import data, we find that countries with lax environmental regulations tend to specialize in the production of polluting goods and export them to Korea.

Our paper contributes to the literature in a number of ways. First, the strong evidence from South Korea extends the validity of the pollution haven behavior to newly developed countries. In particular, the pollution haven incentive can be magnified in a transitional phase where clean technologies have not been adopted despite strengthened environmental regulations than in a phase where environmental regulations have already induced self-perpetuating clean technology innovation and adoption. This prediction is also in line with the recent literature on the directed technical change toward clean technology (Acemoglu et al., 2012; Aghion et al., 2012). Secondly, even though the pollution haven hypothesis is testable by examining the pattern of FDI flow (Cole and Elliott, 2005; Eskeland and Harrison, 2003; Hanna, 2010; Javorcik and Wei, 2004; Kellenberg, 2009), trade flow (Broner et al., 2012; Ederington et al., 2005; Grossman and Krueger, 1994; Levinson and Taylor, 2008), or birth of plants (List et al., 2003), no study to our knowledge has looked into different types of industry activity at the same time. We investigate those three different industry activities to confirm a consistent behavior among one another and thereby provide a clearer picture of industry relocation occurring in a country. The third contribution is methodological. Our strategy is particularly useful when investigating FDI at the cross-country level, because the decision process of foreign investment is very sensitive not only to the industry structure of home countries but also to the characteristics of host countries, which generates a variety of country- and industry-level (unobserved) heterogeneity.[6]

The remainder of this paper is organized as follows. Section 2 describes our data and discusses some important features of the data. In Section 3, we set up empirical models and address related econometric issues. Section 4 presents estimation results with their robustness checks. Section 5 concludes.

2. Data and descriptive statistics

This section takes a deeper look at our data on three key variables (FDI outflow, country-level relative laxity of environmental regulations, industry-level pollution intensity) and highlights some distinct advantages of the data in the assessment of the pollution haven hypothesis.

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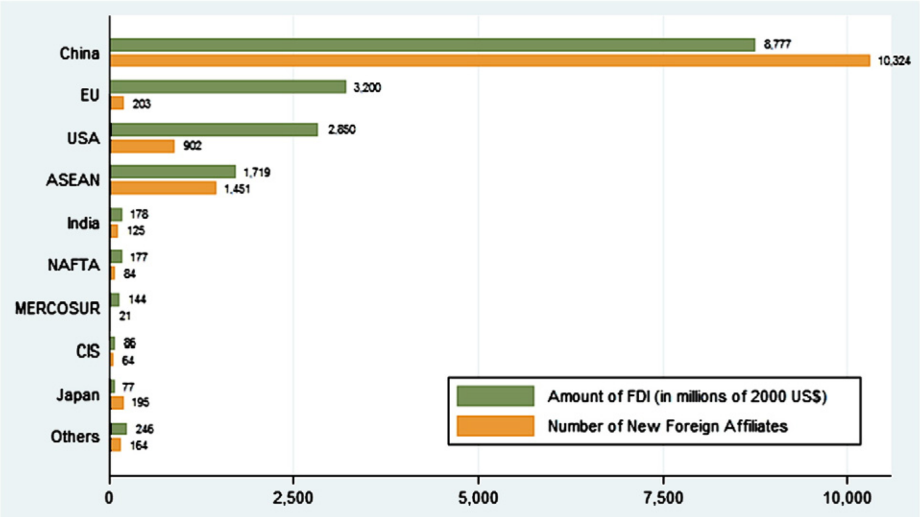
[3] The obvious effect of clean technology reducing pollution emission is often referred to as the 'technique effect' (Antweiler et al., 2001). Our focus here is not the technique effect, but the deterrent effect of clean technologies on the migration of polluting industries. In accordance with the two different effects, Levinson (2009) finds that the majority of air pollution reduction in the U.S. manufacturing industry from year 1987 to 2001 is attributed to the advancement in production and abatement technologies, while only one-tenth can be explained by the industry shifts overseas.

[4] Detailed statistics are provided in Section 2.

[5] Rajan and Zingales (1998) first use this interaction strategy to examine whether countries with a more developed financial system provoke a disproportionate growth in industries that rely more intensively on external finance. The strategy has been popularly applied in the empirical trade literature to identify sources of comparative advantage, including factor endowments (Romalis, 2004) and contract enforcement (Nunn, 2007).

[6] A few papers use the same DID-type strategy as ours within the literature. For example, Broner et al. (2012) apply it to look at import pattern, while Hanna (2010) modifies the strategy to examine the relocation of U.S. plants abroad. However, the strategy has not been applied to FDI at the cross-country level.



Note: NAFTA excludes USA. See Table B1 in Appendix B for the membership of countries.
Source: The Export-Import Bank of Korea

Fig. 1. Distribution of South Korean outward FDI by region, 2000–2007.

Information on data sources and measures of variables are provided with relevant statistics in Appendix B.

2.1. South Korean outward FDI

We employ data on South Korean manufacturing FDI outbound to 50 host countries.[7] This data originates from the Export–Import Bank of Korea which records all cases of foreign investment made by Korea-headquartered firms. Our sample period spans from 2000 to 2007, for which the data on environmental laxity is available. The original FDI data is classified by the Korean Standard Industrial Classification (KSIC) 9th edition, which is converted into the International Standard Industrial Classification (ISIC) Revision 4. In the end, we have 121 four-digit industries in our sample, which is fairly disaggregated compared to data used in prior studies (e.g., Cole and Elliott, 2005; Kellenberg, 2009; Keller and Levinson, 2002).

South Korea has a relatively young history of outward FDI. The country had only about 30 active foreign manufacturing affiliates until 1980. Its share of total world outward FDI stock had been less than 0.1% until 1990. After experiencing the Asian financial crisis, Korean foreign investment has rapidly increased in the 2000s. However, its magnitude is still negligible relative to the activities of other major countries: the average Korean share over the sample period remains at 0.3% of total FDI stock and 0.6% of total FDI outflow, while the U.S. had 29% and 18% of total FDI stock and outflow, respectively. Other advanced countries, such as France and the U.K., also have about 10% shares in both stock and outflow.[8] Hence, the influence of Korean FDI on environmental policies in a host country is not likely to be significant.

Fig. 1 provides the total amount of FDI and the number of new-born foreign affiliates during 2000–2007 distributed by region. The figure indicates two noteworthy features of South Korean outward FDI. First, Korean FDI is heavily concentrated toward China. One might think that this concentration may create a spurious causality, i.e., evidence of the pollution haven effect might be simply driven by a China effect. However, this should not be a concern, because we use a difference-in-differences type identification strategy which exploits the cross-industry variation within each country. Our finding is indeed robust when we drop China from our sample.

The more interesting feature is the different pattern between extensive and intensive margins across regions. EU countries and the U.S. are the 2nd and 3rd biggest receivers of Korean FDI in the amount of investment. However, in terms of the number of newly established affiliates, ASEAN countries exceed the figures of the EU and the U.S. The number of new affiliates established in China is also large considering the amount of investment in comparison to the EU and the U.S. This pattern is consistent with the stylized fact that, due to high market entry costs, firms investing in advanced countries are typically large and productive. Europe and the U.S. are also geographically remote from Korea. Hence, we expect that the large amount of FDI toward the advanced countries is mainly driven by a few large Korean firms. On the contrary, China and the ASEAN are newly emerging markets close to Korea with low entry costs which more firms can access. As a result of this pattern, the pollution haven effect may exhibit different signs or economic significances between the extensive and intensive margins. Therefore, we estimate the pollution haven effect at both margins.

2.2. A measure of environmental laxity

Measuring the laxity of environmental regulations has been an issue in the pollution haven literature, especially in cross-country studies. A frequently used measure is pollution abatement costs (e.g., Eskeland and Harrison, 2003; Keller and Levinson, 2002). However, only a few countries have data on pollution abatement costs and they are difficult to standardize for comparison. Moreover, it is often used as a measure of pollution intensity rather than regulatory stringency (e.g., Cole and Elliott, 2005; Manderson and Kneller, 2012).

Our measure of environmental laxity comes from the Global Competitiveness Report (GCR) from 2000 to 2007–2008 editions.[9] There are two advantages in this survey measure. First, it covers a wide range of countries around the world with a standardized method of measurement which allows for direct comparison across countries. Second, as the survey is conducted by representative business executives

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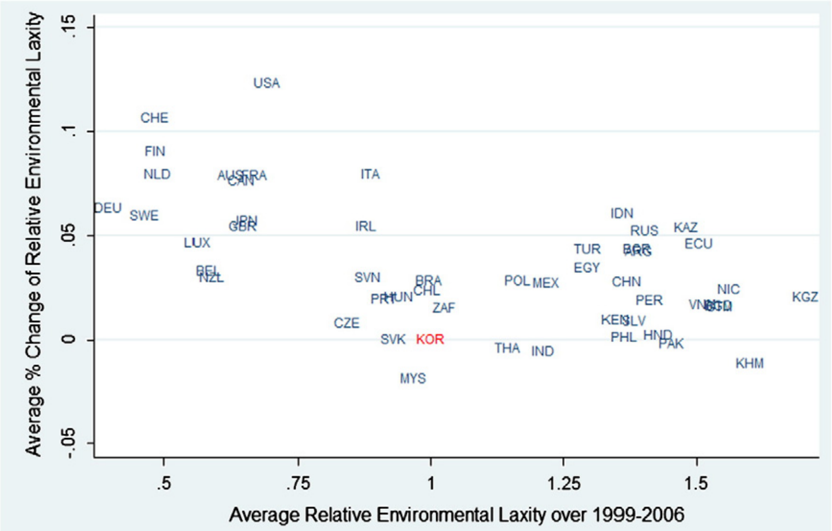
[7] We only consider greenfield mode of FDI in this paper since mergers and acquisitions (M&A) would require a different model specification to estimate. Korean greenfield FDI accounts for 83% of total FDI outflow in manufacturing industry over 2000–2007, whereas M&A are dominant in the worldwide FDI trend during the period.

[8] Data source: UNCTAD Statistics (http://unctadstat.unctad.org/). These statistics are based on the aggregate industry.

[9] This measure has been popularized by recent studies. See, e.g., Kellenberg (2009), Wagner and Timmins (2009), and Manderson and Kneller (2012).



Note: The figure shows South Korea and 50 host countries.

Source: Author's calculation based on the Global Competitiveness Report from 2000 to 2007-2008 edition.

Fig. 2. Average of relative environmental laxity vs. its percentage change over 1999–2006.

located in each country, the measure reflects de facto environmental regulations that are more related to firms' investment decisions. However, the measure is not without its flaws. One concern is that survey respondents may be too sensitive to legislative or macroeconomic shocks. This perception bias may create a non-classical measurement error problem (possibly due to time persistency), but the effect of the measurement error on our estimates is hard to classify.

Fig. 2 plots the average of relative environmental laxity versus its average percent change rate over the years 1999–2006.[10] The X-axis measures, on average, how much laxer a country is than South Korea in environmental regulations. The Y-axis shows the time trend on how relative environmental laxity has changed: countries with positive change rates are getting laxer than South Korea over time, whereas countries with negative change rates are getting tougher. Taken together, the figure indicates that South Korea ranges in the average level in overall environmental laxity during 1999–2006, but the speed at which its environmental standards are strengthened is much higher than other countries.[11] This rapid legislative change must have been a pressure to firms in Korea. As an example, in a survey conducted in 2003 by the Korea Chamber of Commerce & Industry (KCCI), 38% of foreign affiliates located in Korea answered that the rising environmental standards had negatively affected their additional investment in Korea.[12]

2.3. A measure of pollution intensity

An appropriate measure of industry-level pollution intensity would be the total emissions of pollutants by industry. For instance, the Industrial Pollution Projection System (IPPS) in the World Bank estimates the emission of various pollutants across 360 4-digit SIC industries in the U.S. in 1987 (Hettige et al., 1995). Unfortunately, there is no such data available at a 4-digit industry-level in South Korea. We use, instead, energy use per output as our measure of pollution intensity assuming that pollution emissions are monotonically increasing in energy use. Energy use has often been used as a measure of pollution intensity in the literature (e.g., Eskeland and Harrison, 2003; Kahn, 2003). Further, Cole et al. (2005) support the validity of our assumption by directly examining the relationship between energy use and four major air pollutants, sulfur dioxide (SO2), nitrogen oxide (NOx), carbon monoxide (CO), and particulate matter (PM10).

Although not at the 4-digit industry-level, we examine the relationship between pollution emissions and energy use in the aggregate Korean manufacturing industry. Fig. 3 plots emissions (per output) of six pollutants against energy use (per output) from 1999 to 2006. Each plot shows a linear relationship in general. We also examine the correlation between energy use and the pollution intensity measure from the IPPS. The linear correlation coefficient between the two measures is 0.7.

The overall pollution intensity in South Korea is higher than not only those in the most advanced countries, but also other countries with similar levels of development. Part of the reason for the higher pollution intensity is the lenient environmental policies which lasted until the mid-1990s. Korean firms, especially in exporting industries, had benefited from such business-friendly policies freely utilizing old, dirty technologies with little pressure for innovation. Tightening of environmental standards in later years appears to drive gradual innovation and adoption of clean technologies as shown in Fig. 3, but such trend still lags behind other countries largely because of path dependence on old technologies. Accordingly, energy intensity in Korea from 1999 to 2006, measured by the total primary energy consumption per GDP, is 1.07 on average, while the average of OECD countries is 0.72. For carbon intensity, measured by the total emission of carbon dioxide per GDP, South Korea is 0.58, while the OECD average is 0.4. In fact, South Korea ranks 3rd and 4th in terms of carbon and energy intensities, respectively, among 34 OECD countries.[13] Thus, the effect of clean technology adoption that mitigates the pollution haven incentive is less present in our South Korean case.

3. Empirical model

3.1. A conceptual framework

We first introduce a conceptual framework from which our empirical model is developed. It comprises two distinct fundamental

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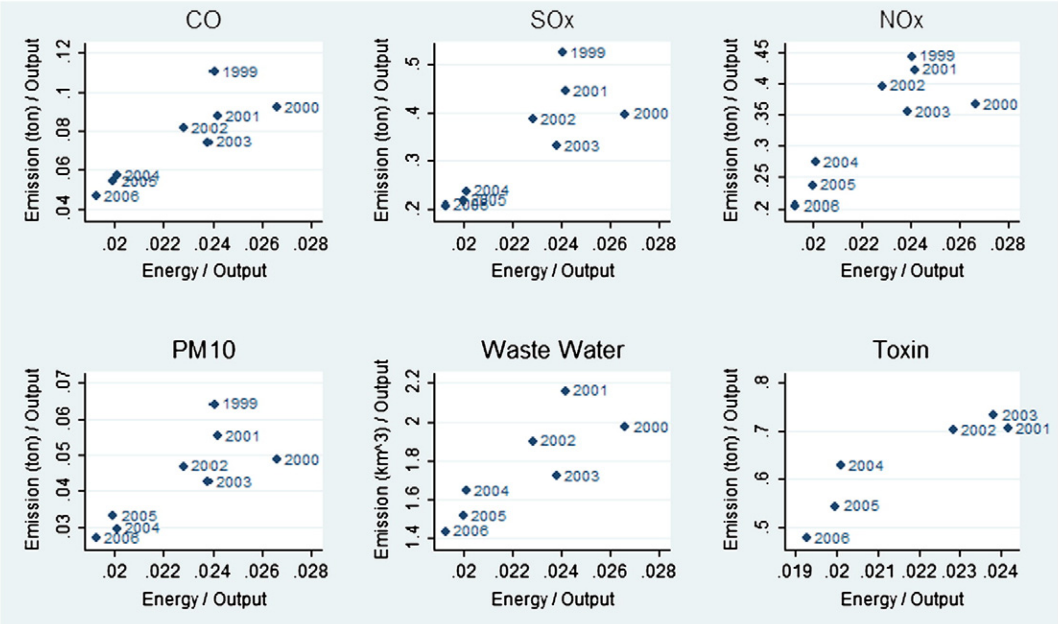
[10] Since the survey is conducted in the beginning of each year, the reported values reflect the environmental laxity in the previous year.

[11] As a relevant indicator, the Environmental Performance Index (EPI) also shows that South Korea ranks 43rd for average environmental performance from 2000 to 2010, but 13th for improvement of environmental performance over the period (Emerson et al., 2012).

[12] Source: The case of environmental regulations hindering business investment (2003, KCCI), in Korean.

[13] Data source: International Energy Statistics from the U.S. Energy Information and Administration (http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm)



Note: Waste water emission for 1999 and toxic emission for 1999 and 2000 are not available.
Energy usage and Output are measured in millions of 2000 US$.
Source: NIER, KOSIS, PRTR for air pollutants, waste water, and toxin, respectively. See Appendix B for more information.

Fig. 3. Relationship between energy use and pollution emissions in South Korea.

motivations in FDI: horizontal and vertical.[14] In a horizontal FDI model, which originates from Markusen (1984), multinational enterprises (MNEs) directly invest in host countries to serve local markets. Hence, MNEs prefer large markets, regardless of industry type. This market-oriented motive faces a proximity-concentration trade-off: multinational sales come at the cost of losing plant-level scale economies (Brainard, 1997). Consequently, large market size, high transport costs, and high trade barriers would encourage horizontal FDI, while large plant-level scale economies would discourage it.

The vertical motivation is pioneered by Helpman (1984) who argues that MNEs fragment their production process to locate in countries with lower production costs. The host country's cheap production factors attract FDI in industries using the factors intensively. In the vertical FDI case, MNEs face a trade-off between proximity and comparative advantage: while MNEs can benefit from cheap production factors in host countries, they have to ship their products back to their home country to serve the domestic market or to proceed with further production processing (Hanson et al., 2005). Hence, abundant factor endowments in host countries would spur vertical FDI, but this incentive would be dampened by high transport costs and high trade barriers in home countries.

Both horizontal and vertical motivations have found support in empirical studies. Carr et al. (2001) test the “knowledge-capital” model in which both horizontal and vertical activities can coexist endogenously. Using U.S. foreign affiliate sales data, they find that both market size and differences in skill endowment are important determinants of foreign affiliate production. Yeaple (2003) examines the pattern of U.S. outward FDI to 39 host countries in 50 manufacturing industries and confirms that FDI is driven by both market- and factor-seeking motivations. In particular, he finds a chain proposition of comparative advantage in skilled labor: skill intensive industries tend to invest more in skilled-labor abundant countries, whereas non-skilled labor intensive industries invest more in labor abundant countries.

3.2. Model specification

The baseline model includes the horizontal and vertical motivations in the following way:

$$E[FDI_{cit}|X,\ \Delta] = exp(\alpha Horizontal_{cit} + \beta Vertical_{cit} + \Delta)\ . \tag{1}$$

In the model, the conditional expectation of a country's outward FDI to host country c in industry i at year t is an exponential function of the two motivations and a set of unobserved effects (Δ). Explanatory variables, $X = \{X_{cit}\}_{t=1}^{T}$, are assumed strictly exogenous conditional on the unobserved effects so that only contemporaneous covariates appear on the right hand side of Eq. (1). FDI_{cit} is measured by either the amount of investment (intensive margin) or the number of new foreign affiliates (extensive margin). Both measures are always non-negative. However, each measure requires a different estimation strategy, since the former is linear whereas the latter is not. All covariates in the two motivations are lagged one year. Lagged covariates are appropriate if a multinational's foreign investment decision for year t is made based on information available at the end of year $t - 1$.[15]

The horizontal motive includes the market size of host country (mkt_{ct}), similarity between home and host country (sim_{ct}), average plant-level scale economies in an industry (SE_{it}), and host country tariff ($Htariff_{cit}$).[16] Thus,

$$\alpha Horizontal_{cit} = \alpha_1 mkt_{ct} + \alpha_2 sim_{ct} + \alpha_3 SE_{it} + \alpha_4 Htariff_{cit}\ . \tag{2}$$

As explained, a positive sign is expected of α_1 and α_4, and a negative sign of α_3. The similarity term, sim_{ct}, is increasing when home and host country c converge in terms of GDP. The greater the convergence, market access motive to country c would appear greater. Hence, α_2 is expected to be positive.

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[14] Recent studies emphasize the emergence of more complex versions of FDI, such as export platform or complex vertical FDI (e.g., Ekholm et al., 2007). However, we only focus on pure horizontal and vertical FDIs for analytical simplicity.

[15] Using present values in covariates does not change our results.

[16] Formal definitions of variables are given in Appendix B.

Four sources of comparative advantage explain the vertical motive: environmental laxity and three factor endowments. Specifically, we include relative environmental laxity in host country *c* to home country ($rlax_{ct}$), relative capital abundance (rkl_{ct}), relative skill abundance (rhl_{ct}), and relative raw material abundance (rml_{ct}). Each factor endowment is scaled by unskilled labor. These country characteristics are then interacted with pollution intensity (PI_{it}), capital intensity (KI_{it}), skill intensity (HI_{it}), and raw material intensity (MI_{it}), respectively. Home country's tariff on country *c* ($Ktariff_{cit}$) is also included. Hence,

$$\begin{aligned}\beta Vertical_{cit} = {} & \beta_1 rlax_{ct} + \beta_2 rlax_{ct} PI_{it} + \beta_3 PI_{it} + \beta_4 rkl_{ct} + \beta_5 rkl_{ct} KI_{it} \\ & + \beta_6 KI_{it} + \beta_7 rhl_{ct} + \beta_8 rhl_{ct} HI_{it} + \beta_9 HI_{it} + \beta_{10} rml_{ct} \\ & + \beta_{11} rml_{ct} MI_{it} + \beta_{12} MI_{it} + \beta_{13} Ktariff_{cit}\,. \end{aligned} \qquad (3)$$

By including interaction terms, we identify sources of comparative advantage in a difference-in-differences type strategy. The pollution haven effect is captured by β_2. A positive β_2 means that, as environmental laxity in a host country *c* increases relative to home country, *c* receives a disproportionately greater amount of FDI from polluting industries in comparison to non-polluting industries.[17] Similarly, a positive β_5 implies that a country with richer capital stock than South Korea would attract more investments in capital-intensive industries. All coefficients on interaction terms are, thus, expected to be positive, while the coefficient on home country tariff is negative. The signs of coefficients on main terms of country and industry characteristics are less clear due to aggregation bias and unobserved heterogeneity. The next subsection explains these econometric issues in more detail.

3.3. Econometric issues

In order for the estimated coefficient, $\hat{\beta}_2$, to be interpreted as a causal differential effect of environmental laxity on FDI across industries, the baseline model must satisfy the strict exogeneity assumption. There are some concerns, however, that may invalidate this assumption. We list such concerns below and discuss how they are dealt with.

3.3.1. Aggregation bias

Although the variable at interest is the interaction term of environmental laxity, the pollution haven effect can also be identified by its main term. The coefficient, β_1, in the baseline model captures the average effect of environmental laxity on the aggregate FDI from all industries. We expect that β_1 is likely to be positive but may be insignificant economically if there exists sizable differences in pollution intensity across industries (in home country), as such differences may induce conflicting responses to a same environmental policy. For example, clean industries may reduce FDI in response to an increase in relative environmental laxity, because they require clean materials or simply prefer a clean environment. Then, the pollution haven incentives of dirty industries are masked by conflicting incentives of clean industries in aggregate-level data.[18]

The same argument applies to β_2, so long as heterogeneity in pollution intensity is large enough across firms within each industry. Furthermore, industry-level pollution intensity may be systematically undermeasured if the most polluting firms exit the market or migrate overseas owing to environmental regulations (Levinson and Taylor, 2008). Our 4-digit industry-level FDI data reduces (though not solves) these biases when compared to prior studies which use 2-digit industry-level data (Kellenberg, 2009; Keller and Levinson, 2002; Millimet and Roy, 2011; Wagner and Timmins, 2009). Note that even in studies using firm- or plant-level FDI data, pollution intensity is still measured at the industry level (Hanna, 2010; Javorcik and Wei, 2004).

3.3.2. Effect of factor endowments

We have three factor endowments as sources of comparative advantage in Eq. (3). Including factor endowments in the model is important for evaluating the pollution haven hypothesis. In particular, polluting industries tend to be capital intensive, while most capital-abundant countries impose stringent environmental standards. As Copeland and Taylor (2003, p. 213) conclude, "since comparative advantage is determined jointly by differences in pollution policy and differences in factor endowments, most of the predictions of the pollution haven model can be reversed in a world where factor endowments matter… Dirty good production can remain in high-income countries despite much tighter regulation if these cost disadvantages are offset by other factors." Cole and Elliott (2005) focus on this issue predicting that countries with (relatively) lenient environmental regulations which are rich in capital are the most likely to be pollution havens (Brazil and Mexico in their sample). They find that U.S. FDI in these countries increases in industry-level pollution intensity.

We generalize Cole and Elliott's case study to a cross-country analysis by including four interaction terms in the model. Specifically, we model the marginal effect of pollution- and other factor-intensities to be a conditional function of the environmental laxity and factor abundances of a country, respectively. If the country has lax environmental regulations and a rich capital stock, it reduces to the same analysis as Cole and Elliott (2005). In this way, the baseline model unravels the opposing forces between environmental laxity and factor endowments in each country.

3.3.3. Unobserved heterogeneity

The baseline model may suffer from omitted variable bias due to unobserved heterogeneity. According to a recent survey by Blonigen and Piger (2011), dozens of country-level determinants of FDI have been identified as significant in the literature (e.g., business cycle, regional trade agreement, infrastructure, corruption, political stability, consumer prices, market capitalization). However, studies have selected a limited set of covariates in their model. This is problematic because, as Blonigen and Piger (2011, p. 4) argue, "inference regarding the effects of included covariates can depend critically on what other covariates are included versus excluded," and our model is not an exception. There are also many important industry-level determinants of FDI that are not accounted for in the baseline model. Notable examples include the degree of productivity dispersion (Helpman et al., 2004) and footlooseness (Ederington et al., 2005). R&D intensity and industry-wise business regulations are also important but not observable in our model.

To resolve this issue, we control for all unobservable (time-varying) country- and industry-level determinants of FDI, i.e., they are all subsumed in country-year and industry-year unobserved effects in Δ in Eq. (1). These unobserved effects are then controlled for by either fixed effects or correlated random effects estimation strategy. This strategy is however possible only at the cost of losing the main term of environmental laxity from estimation, since it is also a country characteristic to be subsumed in the country-year unobserved effect.

3.3.4. Endogeneity of environmental regulations

Environmental regulations in home and host countries may be endogenous in our FDI model for different reasons. One reason is the reverse causality of FDI on environmental policies. For example, policymakers in host (home) country may want to strengthen or weaken environmental standards in response to inward (outward) foreign investment in polluting industries (List et al., 2003). Another example would be that foreign polluting firms may lobby policymakers to lower environmental regulations in host countries (Cole et al., 2006). Other typical reasons for the endogeneity problem include the

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[17] A more technical interpretation is that the elasticity of FDI to relative environmental laxity is linearly increasing in pollution intensity.

[18] Owing to the same reason, coefficients on the main terms of factor endowments are confounded.

Table 1
Effect of environmental laxity on the amount of FDI.

Dependent variable: *ln*(*TINV*$_{cit}$)	(1)	(2)	(3)	(4)	(5)
Environmental laxity × pollution intensity	0.166	0.526***	0.064	0.164	0.375***
	(0.104)	(0.135)	(0.103)	(0.104)	(0.139)
Capital abundance × capital intensity	–	0.160***	–	–	0.126***
	–	(0.034)	–	–	(0.036)
Skill abundance × skill intensity	–	–	2.679***	–	1.923**
	–	–	(0.886)	–	(0.822)
Material abundance × material intensity	–	–	–	0.275*	0.105
	–	–	–	(0.152)	(0.158)
Host country tariff rate	0.143	0.157	0.151	0.133	0.156
	(0.099)	(0.097)	(0.097)	(0.099)	(0.095)
Home country tariff rate	−0.181*	−0.231**	−0.203**	−0.185*	−0.238**
	(0.106)	(0.108)	(0.101)	(0.105)	(0.106)
Observations	3196	3196	3196	3196	3196
Within R-squared	0.472	0.478	0.477	0.473	0.481

Notes: All estimations include country-year and industry-year fixed effects. Covariates are log transformed. Robust standard errors two-way clustered at country-industry level and at year level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

measurement error in environmental laxity and omitted variables correlated with the interaction term of environmental laxity.

Unfortunately, we cannot do much in our analysis to deal with the reverse causality and the measurement error problem.[19] Regarding the omitted variables, despite controlling for all country- and industry-specific unobserved heterogeneity, it is possible that there are other important but omitted determinants of FDI varying at country-industry-year level. For example, there may be other sources of comparative advantage, beside factor endowments, that confound the pollution haven effect. We will test whether the inclusion of additional controls in the model changes our finding in our robustness checks. Besides, we allow the error structure to be arbitrarily correlated within country-industry pairs (or countries) so that our inference is robust to such correlation of errors.

4. Estimations and results

4.1. Effect on the amount of FDI

When the dependent variable, FDI_{cit}, is measured by the total amount of investment ($TINV_{cit}$), Eq. (1) can be log-linearized to obtain a linear panel data model. The estimation equation is given as:

$$ln(TINV_{cit}) = \alpha Horizontal_{cit} + \beta Vertical_{cit} + \Delta + \epsilon_{cit}\ . \qquad (4)$$

Standard fixed effects (FE) estimation can be applied to Eq. (4) which allows for the set of unobserved effects, Δ, to be correlated with observed variables. We estimate Eq. (4) with four different configurations of fixed effects in Δ: (i) country, industry, and year fixed effects, (ii) country-industry and year fixed effects, (iii) country-year and industry-year fixed effects, and (iv) country-industry, country-year, and industry-year fixed effects. The first configuration is the most basic. The second configuration captures more unobserved heterogeneity than the first, but given that both country and industry characteristics vary little over time, the country-industry fixed effect absorbs most country-by-industry variations and the within-transformed model may perform poorly. The fourth configuration is not desirable for the same reason. Indeed, we confirm in Appendix A that the estimated coefficients with the configurations (ii) and (iv) are mostly statistically insignificant.

The third configuration is preferred for several reasons. First of all, it captures many important unobserved determinants of FDI without sacrificing the variation necessary in observables. Second, it complies with the purpose of this paper. Since this paper looks at FDI differences in polluting versus non-polluting industries for a given level of environmental laxity, we want to exploit the cross-industry variation within each country-year pair. Third, Eq. (4) is nicely simplified with the third configuration so that it becomes similar to a trade flow model popularized by Romalis (2004). Indeed, the equation reduces to

$$\begin{aligned} ln(TINV_{cit}) = {} & \beta_2 rlax_{ct} PI_{it} + \beta_5 rkl_{ct} KI_{it} + \beta_8 rhl_{ct} HI_{it} + \beta_{11} rml_{ct} MI_{it} \\ & + \alpha_4 Htariff_{cit} + \beta_{13} Ktariff_{cit} + \lambda_{ct} + \psi_{it} + \epsilon_{cit} \qquad (5) \end{aligned}$$

where λ_{ct} is a country-year fixed effect and ψ_{it} is an industry-year fixed effect. Note that all main terms of country- and industry-specific characteristics are subsumed in these two high-dimensional fixed effects, leaving us with only four interactions and two tariff variables. We will also directly apply Eq. (5) to Korean import data and assess the pollution haven hypothesis via trade patterns as well.

Table 1 reports estimation results of Eq. (5). We have 3196 observations in the final sample. Robust standard errors are two-way clustered at the country-industry level and at the year level. Two-way clustering provides valid inference when serial correlation exists within each country-industry pair or when correlation exists across regions within each year. Since Eq. (5) does not include a country-industry fixed effect, standard errors robust to serial correlation (and spatial correlation) are particularly desirable. When only environmental laxity is included as a determinant of comparative advantage, we find no evidence of a pollution haven effect in column (1). However, we find a statistically significant pollution haven effect when capital is included in column (2). This highlights the capital-seeking incentive as a major confounding effect in identifying the pollution haven effect. Physical capital and skill abundance by themselves are found to be a significant determinant of comparative advantage in FDI in columns (2) and (3), respectively.

Environmental laxity, capital abundance, and skill abundance are jointly important in shaping the pattern of FDI flows in column (5). Further, their economic significances are comparable to each other. The magnitude of the estimate reflecting the pollution haven effect indicates that, among other things being equal, a host country increasing its environmental laxity (relative to Korea) by one standard deviation from the mean would attract 12.4% more foreign investment from a Korean industry one standard deviation above the mean pollution intensity than an industry at the mean pollution intensity. Roughly speaking, this implies that had Brazil relaxed its environmental stringency akin to Pakistan's level, it would have received 12.4% more investment from Korean manufacturers of plastics and synthetic rubber in primary

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[19] In an effort to avoid these problems, we use an instrumental variable (IV) strategy in Chung (2012). Lagged PM10 level and tuberculosis notification rate across countries are used to instrument for environmental laxity. Although the IV estimates indicate a pollution haven effect to be as significant both statistically and economically as the fixed effect estimates obtained in this paper, we do not report the results since the two IVs may also be subject to endogeneity.

Table 2
Other sources of comparative advantage in FDI.

Dependent variable: $ln(TINV_{cit})$	(1)	(2)	(3)	(4)
Environ. laxity × pollution intensity	0.369***	0.414***	0.404***	0.455***
	(0.128)	(0.142)	(0.135)	(0.118)
Capital abundance × capital intensity	0.129***	0.146***	0.123***	0.138***
	(0.048)	(0.037)	(0.036)	(0.048)
Skill abundance × skill intensity	1.905**	1.701**	1.980**	1.789**
	(0.813)	(0.850)	(0.860)	(0.892)
Material abundance × material intensity	0.105	0.319	0.104	0.321
	(0.157)	(0.217)	(0.157)	(0.218)
Contract enforcement × machinery intensity	−0.069	–	–	0.122
	(0.521)	–	–	(0.534)
GDP per capita × value added	–	0.463**	–	0.471**
	–	(0.219)	–	(0.223)
Material abundance × pollution intensity	–	–	0.024	0.025
	–	–	(0.058)	(0.058)
Host country tariff rate	0.155	0.155	0.156*	0.157*
	(0.095)	(0.094)	(0.095)	(0.094)
Home country tariff rate	−0.239**	−0.234**	−0.235**	−0.229*
	(0.110)	(0.115)	(0.106)	(0.118)
Observations	3196	3196	3196	3196
Within R-squared	0.481	0.482	0.481	0.482

Notes: All estimations include country-year and industry-year fixed effects. Covariates are log transformed. Robust standard errors two-way clustered at country-industry level and at year level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

forms relative to manufacturers of grain mill products. For capital endowment, a host country one standard deviation above the mean capital abundance would attract 16.5% more FDI from an industry one standard deviation above the mean capital intensity (relative to the mean capital intensity industry). Similarly, a host country one standard deviation above the mean skill abundance is associated with 11.4% increase of FDI from an industry one standard deviation above the mean skill intensity. Thus, the effect of environmental laxity is as significant as factor endowment effects on the amount of South Korean FDI. While we do not explicitly interpret the marginal effect of tariff rates, their signs are consistent with our prediction.

We conduct several robustness checks of our finding. While other results are presented in Appendix A to keep our discussion focused, here we address a few critical concerns and report the relevant results in Table 2. Particularly, the empirical international trade literature has found some remarkable sources of comparative advantage beside factor endowments.[20] Nunn (2007), for instance, has emphasized the role of contractual frictions on trade flows: if final good producers had to commit a non-contractible, relationship-specific investment, they would prefer to invest in countries where the quality of contract enforcement is high in order to avoid a hold-up problem. Hence, we test for contract enforcement as an additional source of comparative advantage in FDI by including in Eq. (5) the interaction of country-level contract enforcement and industry-level relation specificity.[21] Including the interaction term helps clarify an important concern. Since environmental standards can be viewed as one aspect of institutional quality as is contract enforcement, our estimates may merely be picking up an effect of institutional quality interacted with an industry characteristic that is correlated with pollution intensity. In fact, the correlation between environmental laxity and contract enforcement is −0.91 in our sample. Also, the correlation between pollution intensity and machinery intensity is 0.38. Column (1) in Table 2 reports the result with the interaction term. Contract enforcement appears to be neither a strong determinant of Korean FDI nor a factor affecting the estimate on the pollution haven effect.

Column (2) considers the possibility that high income countries may receive a disproportionate amount of FDI in high-tech and high value-added industries, which is seemingly apparent in Fig. 1. Moreover, since GDP per capita is highly correlated with institutional quality and usually considered as a determinant of environmental policies, the same concern for contract enforcement applies here, too. To account for this possibility, relative GDP per capita between host and home country is interacted with industry-level value-added (per output). It turns out that GDP per capita does attract high value-added industries at the 5% significance level, but that effect does not confound the pollution haven effect.

Column (3) addresses a somewhat controversial argument that geographically large countries with a small population may have a comparative advantage in pollution. If population is sparse while land is large, people may feel less sensitive to pollution and their environmental regulations may be lax. These countries tend to have rich natural resources as we proxy raw material abundance by land area per labor force. Moreover, since our measure of pollution intensity is energy use, the estimate on the environmental laxity interaction term may be capturing the effect of land size (relative to population) attracting FDI from fuel-intensive industries. If that is the case, the interaction term of raw material abundance and pollution intensity would control for such confounding effects. However, the result in column (3) indicates no existence of such effect, while the pollution haven effect remains strong.

4.2. Effect on the number of new affiliates

So far, our focus has been the effect of environmental laxity on the total amount of foreign investment, i.e., the intensive margin of FDI. As shown in Section 2, however, the pattern of FDI may be systematically different between the intensive and extensive margins. Furthermore, our finding at the intensive margin could be driven by few polluting firms that invest large amounts, with the majority of firms not responding to environmental policies. This subsection, therefore, assesses the pollution haven hypothesis at the extensive margin of FDI by investigating how many firms are actually attracted by a foreign country's environmental laxity so that they migrate into that country.

Our baseline model in Eq. (1) is still useful for this assessment. The only difference is that FDI_{cit} is now measured by the number of new foreign affiliates ($NAFF_{cit}$). Since the dependent variable is count data, FE estimation given a log-linear transformation of Eq. (1) is not

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[20] Our choice of additional controls presented here is based on intuition that certain country and industry characteristics may be significantly correlated with environmental laxity and pollution intensity, respectively.

[21] Our measure of contract enforcement is the 'rule of law' indicator from the Worldwide Governance Indicators (WGI) used in Nunn (2007). Relation specificity of an industry is measured by machinery intensity following Nunn and Trefler (2013). While other kinds of capital, such as buildings and automobiles, have outside values, machinery is only useful in the production process. Hence, machinery stock relative to total capital stock (i.e., machinery intensity) gages how much that industry makes relationship-specific investments.

Table 3
Effect of environmental laxity on the number of new foreign affiliates.

Dependent variable: $NAFF_{cit}$	(1)		(2)		(3)	
	Poisson	NB2	Poisson	NB2	Poisson	NB2
$\ln(NAFF_{cit\text{–}\mathrm{i}})$	–	–	0.516^{***}	0.477^{***}	0.493^{***}	0.477^{***}
	–	–	(0.020)	(0.030)	(0.020)	(0.030)
Environ. laxity × pollution intensity	0.334^{***}	0.471^{***}	0.277^{***}	0.326^{***}	0.362^{***}	0.380^{***}
	(0.072)	(0.106)	(0.062)	(0.072)	(0.068)	(0.077)
Capital abundance × capital intensity	0.156^{***}	0.190^{***}	0.063^{***}	0.080^{***}	0.066^{***}	0.062^{**}
	(0.028)	(0.032)	(0.022)	(0.024)	(0.024)	(0.026)
Skill abundance × skill intensity	−0.464	0.829	0.752^{**}	1.104^{***}	0.788^{**}	1.409^{***}
	(0.440)	(0.563)	(0.364)	(0.410)	(0.387)	(0.433)
Material abundance × material intensity	-0.232^{*}	-0.294^{**}	0.101	0.168^{**}	0.106	0.160^{*}
	(0.119)	(0.125)	(0.085)	(0.085)	(0.099)	(0.097)
Contract enforcement × machinery intensity	–	–	–	–	0.077	0.439^{**}
	–	–	–	–	(0.198)	(0.217)
GDP per capita × value added	–	–	–	–	−0.078	−0.091
	–	–	–	–	(0.102)	(0.110)
Host country tariff rate	0.338^{***}	0.287^{***}	0.152^{***}	0.190^{***}	0.129^{**}	0.188^{***}
	(0.063)	(0.078)	(0.052)	(0.057)	(0.052)	(0.056)
Home country tariff rate	0.175	−0.121	-0.135^{*}	-0.216^{***}	-0.133^{*}	-0.214^{***}
	(0.108)	(0.100)	(0.074)	(0.072)	(0.075)	(0.071)
$\widehat{NaFF}_{cit}$	1.66	0.20	5.77	0.22	6.44	0.26
Observations	44,809		44,809		44,809	

Notes: All estimations include the averages of observed covariates across industries $(\overline{X}_{c\cdot t})$ and across countries $(\overline{X}_{\cdot it})$, the averages of the number of new foreign affiliates in the initial year across industries $\left(\overline{NAFF}_{c\cdot 0}\right)$ and across countries $\left(\overline{NAFF}_{\cdot i0}\right)$. Covariates are log transformed. Standard errors in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

desirable. We instead estimate the model by panel Poisson and Negative Binomial (NB2) regressions using a correlated random effects approach (Wooldridge, 2005). This estimation strategy requires an assumption on the probability distribution of unobserved effects in Δ. First, as in the FE estimation, we keep using country-year and industry-year unobserved effects as the preferred configuration, i.e., $\Delta = \lambda_{ct} + \psi_{it}$. Next, suppose that the two unobserved effects can be specified as following:

$$\Lambda_{ct} = exp(\lambda_{ct}) = \theta_{ct} exp(\gamma_0 + \gamma_1 ln(\overline{NAFF}_{c\cdot 0}) + \gamma_2 \overline{X}_{c\cdot t})$$
$$\Psi_{it} = exp(\psi_{it}) = \kappa_{it} exp(\delta_0 + \delta_1 ln(\overline{NAFF}_{\cdot i0}) + \delta_2 \overline{X}_{\cdot it}) \tag{6}$$

where both θ_{ct} and κ_{it} are independent of $(NAFF_{ci0}, X_{cit})$ and $\theta_{ct}, \kappa_{it} \sim Gamma(\eta, \eta)$ with mean 1 and variance $1/\eta$. $\overline{X}_{c\cdot t}$ and $\overline{X}_{\cdot it}$ are vectors of the averages of all observed covariates within country-year and industry-year pairs, respectively. Likewise, $\overline{NAFF}_{c\cdot 0}$ and $\overline{NAFF}_{\cdot i0}$ are the averages of the number of new foreign affiliates across industries and countries in the initial year, respectively. These initial values are necessary to incorporate state dependence in the model. Intuitively, Eq. (6) is analogous to the Mundlak correction in a linear panel, implying that the two unobserved effects λ_{ct} and ψ_{it} depend only on the averages of covariates and initial values (Mundlak, 1978). Inserting Eq. (6) into Eq. (1) produces

$$\begin{aligned} &E[NAFF_{cit} | NAFF_{cit-1}, \cdots, NAFF_{ci0}, X, \Delta] \\ &\quad = \Lambda_{ct} \Psi_{it} exp\{\rho ln(NAFF_{cit-1}) + \alpha Horizontal_{cit} + \beta Vertical_{cit}\} \end{aligned} \tag{7}$$

where the dynamic nature of FDI is reflected by the lagged dependent variable. Horizontal and vertical motives include observed covariates that vary over country-industry-year level as in Eq. (5).[22] Since we have specified the densities of Λ_{ct} and Ψ_{it}, we know the joint density of $\{NAFF_{cit}\}_{t=1}^{T}$ conditional on $(NAFF_{ci0}, X, \theta_{ct}, \kappa_{it})$ from Eq. (7). By integrating θ_{ct} and κ_{it} out with respect to the $Gamma(\eta, \eta)$ density, we can obtain the conditional density of $\{NAFF_{cit}\}_{t=1}^{T}$ given $(NAFF_{ci0}, X)$. Then, the log-likelihood function derived from the conditional density has the same structure as in the standard random effects Poisson model with Gamma heterogeneity. This permits us to estimate Eq. (7) by standard panel Poisson or NB2 regression with random effects. See Wooldridge (2005) for a more detailed explanation.

Estimation results with Poisson and NB2 regressions are reported in Table 3. The sample size is the multiplication of the number of sample countries, industries, and years. This would generate 50 × 121 × 8 = 48,400 observations, but we only have 44,809 due to some missing values. Note that the number of observations with one or more new affiliates is only 2478, which accounts for about 6% of the sample size. These excessive zeros in the data induce over-dispersion of the dependent variable, as is apparent from the sample summary statistics table in Appendix B. The over-dispersion can also be generated by unobserved heterogeneity as specified in Eq. (6). Accordingly, the predicted numbers of new foreign affiliates (shown at the bottom of the table) are much higher under Poisson distribution than under NB2 distribution, although magnitudes of estimated coefficients are not that different. This reveals that the equi-dispersion assumption in Poisson model is too restrictive for our data.

Across all columns in Table 3, environmental laxity, along with capital abundance and skill abundance, is found to be an important source of comparative advantage, which is consistent with our result deduced at the intensive margin. Thus, the pollution haven effect is statistically significant at the extensive margin as well. The effects of host country import tariffs are also statistically significant in all columns, unlike in the intensive margin case. We prefer the specification in column (2) to column (1), because the role of the lagged dependent variable appears important at the extensive margin. This makes sense in that an initial investment decision would be sensitive to recent FDI trends or agglomeration economies. Column (2) is also favored over column (3) where the differential effects of contract enforcement and GDP per capita remain relatively insignificant.

To evaluate the economic significance of the pollution haven effect based on the result in column (2)-NB2, we exponentiate the coefficient estimate on the environmental laxity interaction term. This exponentiated coefficient is known as the incidence rate ratio, the ratio by which the dependent variable changes for one unit change in an explanatory variable. It thus presents the marginal effect of the interaction term on a multiplicative scale, like the odds ratio in a logit model, so that

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[22] Alternatively, we can include all observed covariates in Eqs. (2) and (3) as observed heterogeneity. Estimation results are qualitatively same.

Table 4
Effect of environmental laxity on import flows.

Dependent variable: $ln(IMPORT_{cit})$	(1)	(2)	(3)	(4)
Environ. laxity × pollution intensity	0.397***	0.446***	0.471***	0.542***
	(0.083)	(0.083)	(0.086)	(0.086)
Capital abundance × capital intensity	0.048	0.029	0.092***	0.068*
	(0.033)	(0.036)	(0.033)	(0.035)
Skill abundance × skill intensity	3.976***	4.046***	3.918***	4.009***
	(0.441)	(0.446)	(0.440)	(0.444)
Material abundance × material intensity	0.275***	0.273***	0.360***	0.363***
	(0.077)	(0.077)	(0.078)	(0.078)
Contract enforcement × machinery intensity	–	0.454*	–	0.612**
	–	(0.270)	–	(0.273)
GDP per capita × value added	–	–	0.430***	0.454***
	–	–	(0.097)	(0.099)
Host country tariff rate	−0.075	−0.073	−0.072	−0.069
	(0.066)	(0.066)	(0.065)	(0.065)
Home country tariff rate	−0.756***	−0.757***	−0.726***	−0.726***
	(0.176)	(0.175)	(0.173)	(0.172)
Observations	24,786	24,786	24,786	24,786
Within R-squared	0.437	0.438	0.440	0.440

Notes: All estimations include country-year and industry-year fixed effects. Covariates are log transformed. Robust standard errors two-way clustered at country-industry level and at year level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

we can interpret the marginal effect in the same way we did in the intensive margin analysis. To be specific, the effect of one standard deviation (σ) increase of environmental laxity from the mean (μ) in a host country on the number of new entering Korean affiliates in an industry with one standard deviation above the mean pollution intensity, relative to the number in an industry with the mean pollution intensity, is expressed as $E\left[\frac{NAFF \mid \mu_{rlax}+\sigma_{rlax},\ \mu_{PI}+\sigma_{PI}}{NAFF \mid \mu_{rlax},\ \mu_{PI}+\sigma_{PI}} \Big/ \frac{NAFF \mid \mu_{rlax}+\sigma_{rlax},\ \mu_{PI}}{NAFF \mid \mu_{rlax},\ \mu_{PI}}\right] = exp(\beta_2\sigma_{rlax}\sigma_{PI}) \approx 1.11$. Take our earlier example where Brazil lowered its environmental standards to the level of Pakistan's. The incidence rate ratio tells us that roughly 1.11 times as many new Korean affiliates would enter Brazil in manufacturing of plastics & synthetic rubber as would enter in manufacturing of grain mill products. Given that the predicted number of new affiliates is 0.22 in column (2)-NB2, this change appears to be economically significant.

By the same formula, a one standard deviation increase in capital abundance from the mean in a host country would attract 1.1 times more Korean new affiliates in an industry with pollution intensity one standard deviation above the mean than an industry at the mean pollution intensity. The incidence rate ratio for one standard deviation change in both skill abundance and skill intensity is 1.07. Thus, the pollution haven effect exhibits a comparable economic significance to capital and skill endowment effects.

4.3. Comparison with trade data

In this subsection, we provide complementary evidence for the pollution haven effect using trade data. If environmental laxity was a source of comparative advantage, countries with laxer environmental regulations than South Korea would specialize in polluting industries and export polluting goods to Korea. Therefore, we can test for the pollution haven hypothesis by analyzing the pattern of Korean import. This test is worth performing to examine whether the same pollution haven behavior is observed in both FDI and trade in a given country. The test also serves as a validity test of our model specifications and measures of variables by checking whether the directions and magnitudes of estimated coefficients are reasonably consistent with our predictions. Poor consistency between estimation results and our priors would imply poor model specifications or measures of variables.

To implement the analysis, we restrict our trade sample to the same countries, industries, and years as in the FDI analysis. Thus, South Korean import data comprises 50 trading partners in 121 industries from 2000 to 2007. We use the same model in Eq. (5) with the log of total amount of import, $ln(IMPORT_{cit})$, as the dependent variable and apply the fixed effects estimation such that results from FDI and import flow can be compared. We expect the coefficient of the environmental laxity interaction term to be positive and significant, as the laxer environmental regulations a host country has the more polluting goods are likely to be produced and imported to South Korea. Similarly, coefficients for all other sources of comparative advantage (i.e., all other interaction terms) would be positively significant. Tariffs in Korea would clearly chill the volume of imports, while the effect of host country tariffs on Korean import is ambiguous. [23]

Estimation results are presented in Table 4. The import data is originally classified by the Harmonized System (HS) at 6-digit product level. After converting and aggregating into 4-digit industries according to ISIC4, we have 24,786 observations. In all specifications, we find a significant differential effect of environmental regulations across industries in terms of the amount of import flows. Further, the magnitude of coefficient estimates on the environmental laxity interaction is as high as those in Table 1 of the FDI outflow case. Put differently, environmental laxity as a determinant of comparative advantage has a similar economic impact on the amount of FDI outflow and trade flows in relative (percentage) terms. All other five sources of comparative advantage are generally found to be as important determinants of the pattern of trade flows as we predicted. Home country tariffs are shown to be a major deterrent factor of imports.

5. Concluding remarks

This paper supplements the literature on the pollution haven hypothesis by providing new evidence from a country that has rarely been explored. Specifically, we examine the pattern of South Korean outward FDI as well as imports over 2000–2007 to test whether polluting industries in Korea show differing patterns of investment according to the difference in environmental laxity between home and a host country. South Korea has rapidly strengthened environmental standards throughout the 1990s while access to clean technologies was still limited, which in turn magnified the incentive of polluting firms to consider relocating to a pollution haven. Thus, the Korean circumstance provides a good setting to put the pollution haven hypothesis to test.

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[23] The model specification in Eq. (5) (without the two tariff terms) is also used in Broner et al. (2012) for the pattern of the U.S. import flow in 2005. Unfortunately, the quantitative comparison of estimation results between two studies is not possible due to the differences in measurement.

Our finding concludes that the laxity of environmental regulations is both a statistically and economically significant determinant of comparative advantage in FDI at both intensive and extensive margins, which supports the pollution haven hypothesis. The finding also indicates that the same pollution haven behavior consistently appears in the pattern of international trade. Note, however, that the poor treatment of data aggregation, other determinants of comparative advantage, or unobserved heterogeneity can mask the said pollution haven effect. This highlights the importance of a carefully designed empirical model with at least a fairly disaggregated industry-level data to avoid potential econometric problems.

Further research is desirable to extend the validity of the pollution haven hypothesis particularly taking the effect of clean technologies into account. Since we state that the pollution haven behavior will be more clearly observed in countries with lack of clean technologies despite their high environmental standards, investigating such countries would help confirm validity. It would also be interesting to unravel in a model the underlying mechanism of how environmental policies simultaneously affect a firm's decisions on migration and clean technology adoption. In a broader sense, this line of research is expected to deepen our understanding of the pollution haven hypothesis in relation to the economic growth process and the role of clean technologies.

Appendix A. Additional robustness checks

We conduct additional robustness checks to our finding reported in column (5) in Table 1. First, as shown in the data section, South Korean outward FDI is heavily concentrated toward China, a country with lenient environmental standards. A possible concern may be that our finding is simply capturing a China effect. To deal with the concern, we drop China from our sample host countries. Column (1) in Table A.1 presents the regression result of Eq. (5) excluding China. The sample size is now 2510. Contrary to the concern, the estimate suggests that the magnitude of the pollution haven effect is slightly stronger, but the difference is statistically insignificant.

The second test is to use an alternative measure of environmental laxity. A measure of de facto environmental stringency may need to account for how consistently environmental regulations are enforced, since regulation itself could be only nominal without good enforcement. The Global Competitiveness Report 2000 through 2006–2007 editions provide information about the consistency of environmental regulations alongside stringency. We construct an alternative measure of environmental laxity by multiplying regulatory laxity and the reverse degree of consistent enforcement. The estimation result reached by applying the alternative measure is presented in column (2). Observations in 2007 are all dropped due to the lack of information on consistency, which leaves us 2585 observations. The result still supports the pollution haven hypothesis.

Next, we allow for arbitrary clustered errors within countries instead of country-industry pairs. Given that we do not know a prior the error structure of the baseline model, we expect that most correlation of errors within a country could be removed through the country-year fixed effect, λ_{ct}. Still, if Korean FDI which flows into a certain host country is correlated across industries in an arbitrary form, estimated standard errors reported in Table 1 may be biased downward. Column (3) shows the estimation result with robust standard errors two-way clustered at country and year levels. Although the standard error of the environmental laxity interaction term is slightly larger, the coefficient estimate is statistically significant at the 5% level.

In column (4), we estimate the same model, but now having aggregated the data to the 2-digit industry-level in ISIC4, i.e., all industry characteristics and tariffs are averaged over 2-digit industries, while FDI amounts are summed. The sample size is reduced to 1649. This test helps address the concern in the literature that the pollution haven effect may be masked by data aggregation. The result in column (4) suggests that data aggregation at the 2-digit level does conceal the pollution haven incentive of polluting industries which appeared at the 4-digit level.

We compare estimation results with different configurations of fixed effects in column (5), (6), and (7). They are (i) country, industry, and year fixed effects, (ii) country-industry and year fixed effects, and (iii) country-industry, country-year, and industry-year fixed effects, respectively. Since the first two configurations do not subsume time-varying country and industry characteristics, all covariates in the horizontal and vertical motives are included for the estimations. In general, the estimation results clearly indicate the importance of the configuration of fixed effects in identifying the pollution haven effect. The coefficient estimates of the environmental laxity main term are statistically insignificant at the 5% level in both columns (5) and (6), but the insignificance comes as no surprise given the aggregation bias and unobserved heterogeneity explained in Section 3.3. Also, in columns (6) and (7), the country-industry fixed effect absorbs most country-by-industry variation in the environmental laxity (and other) interaction terms leading to estimates that are statistically insignificant. These results all together suggest that the configuration of country-year and industry-year fixed effect is preferred to the other configurations.

Finally, although not reported in this paper, we also consider the dynamic nature of FDI. Since a firm's current investment decision clearly depends on its past investments, no state dependence in our baseline model may be a strong restriction. To account for the dynamic behavior of FDI, we incorporate a lag structure in Eq. (5) assuming that investments in the past few years reflect the recent trend in FDI. The estimation result does not change our finding qualitatively. Interested readers can find the result in Chung (2012).

Table A.1
Additional robustness checks to the baseline result.

Dependent variable: $ln(TINV_{cit})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Environmental laxity	–	–	–	–	1.224*	−0.186	–
	–	–	–	–	(0.629)	(1.096)	–
Environmental laxity × pollution intensity	0.509***	0.246***	0.375**	0.382	0.360***	0.072	0.079
	(0.159)	(0.079)	(0.160)	(0.329)	(0.120)	(0.193)	(0.281)
Pollution intensity	–	–	–	–	−0.252**	0.108	–
	–	–	–	–	(0.116)	(0.118)	–
Capital abundance	–	–	–	–	0.797	1.065	–
	–	–	–	–	(0.791)	(1.216)	–
Capital abundance × capital intensity	0.148***	0.138***	0.126***	0.172**	0.128***	0.086	−0.096
	(0.038)	(0.034)	(0.039)	(0.071)	(0.031)	(0.133)	(0.148)
Capital intensity	–	–	–	–	0.390*	0.664*	–

Table A.1 (*continued*)

Dependent variable: $ln(TINV_{cit})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	–	–	–	–	(0.212)	(0.363)	–
Skill abundance	–	–	–	–	6.225^{*}	2.313	–
	–	–	–	–	(3.193)	(3.885)	–
Skill abundance × skill intensity	1.785^{**}	2.397^{***}	1.923^{**}	2.513^{**}	2.097^{**}	−0.668	−0.501
	(0.829)	(0.816)	(0.800)	(1.279)	(0.898)	(1.545)	(1.129)
Skill intensity	–	–	–	–	0.468	−0.077	–
	–	–	–	–	(0.391)	(0.632)	–
Raw material abundance	–	–	–	–	-2.336^{**}	−0.419	–
	–	–	–	–	(0.956)	(1.841)	–
Material abundance × material intensity	0.140	0.010	0.105	−0.177	0.051	−0.346	0.375
	(0.164)	(0.124)	(0.170)	(0.258)	(0.150)	(0.371)	(0.434)
Raw material intensity	–	–	–	–	0.395	0.658	–
	–	–	–	–	(0.518)	(0.609)	–
Home country tariff rate	−0.156	-0.195^{*}	-0.238^{**}	0.253	-0.273^{***}	−0.009	0.428
	(0.106)	(0.112)	(0.111)	(0.198)	(0.087)	(0.345)	(0.493)
Host country tariff rate	0.151	0.164	0.156^{*}	−1.064	0.154	−0.047	0.260
	(0.104)	(0.110)	(0.095)	(1.710)	(0.094)	(0.325)	(0.295)
Market size	–	–	–	–	2.616^{***}	3.270^{***}	–
	–	–	–	–	(0.896)	(1.210)	–
Similarity	–	–	–	–	2.112^{**}	2.018^{*}	–
	–	–	–	–	(0.852)	(1.066)	–
Plant-level scale economies	–	–	–	–	-0.379^{*}	-0.639^{***}	–
	–	–	–	–	(0.207)	(0.231)	–
Configuration of fixed effects	(iii)	(iii)	(iii)	(iii)	(i)	(ii)	(iv)
Observations	2510	2585	3196	1649	3196	3196	3196
Within R-squared	0.555	0.601	0.481	0.583	0.294	0.117	0.483

Notes: Column (1) drops China from host country sample. Column (2) uses an alternative measure of environmental laxity. Column (3) allows clustering of errors at country and year level. Column (4) has the data aggregated up to 2-digit industry level. Configurations of fixed effects (FEs) are (i) country, industry, & year FEs, (ii) country-industry & year FEs, (iii) country-year & industry-year FEs, and (iv) country-industry, country-year, & industry-year FEs. Covariates are log transformed. Robust standard errors are two-way clustered at country-industry and at year level in parentheses, except in column (3) where clustered at country and at year level. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix B. Data description

50 sample host countries are listed in Table B.1. The sample includes 121 4-digit manufacturing industries classified by the International Standard Industrial Classification (ISIC) Revision 4. All monetary values are converted in 2000 constant U.S. dollar using official exchange rate and Consumer Price Index from the Bureau of Labor Statistics. Assuming that a firm's investment decision is made at the beginning of each year based on the information available at the time, outward FDI is matched with previous year's country and industry characteristics.[24] All variables are log-transformed for our analysis. Summary statistics of data used in each estimation is presented in Table B.2. Also, the correlation coefficients among sample country and industry characteristics are provided in Table B.3.

B.1. South Korean outward FDI, import, and tariff

Outward FDI: from the Oversea Investment Statistics database provided by the Export–import Bank of Korea. Original data is classified by Korean Standard Industry Classification (KSIC) Revision 9.

Import: from the United Nations Conference on Trade and Development (UNCTAD). Original data is classified by the Harmonized System combined.

Home and host country tariff: from the World Integrated Trade Solution (WITS). Original tariff data is classified by the Harmonized System. All tariff rates are added by one before log-transformation.

B.2. Country characteristics

Each host country's characteristic is divided by that of the home country (i.e., South Korea) for measurement in a relative term. For example, relative physical capital abundance is the ratio of physical capital stock per worker in country *c* to that of the home country *k*, i.e., $rkl_{ct} = \frac{K_{ct}/L_{ct}}{K_{kt}/L_{kt}}$. Among the 50 host countries, those ranking in the top and bottom 10th in regard to environmental laxity and factor abundances are listed in Table B.4.

Environmental laxity: data taken from the Global Competitiveness Report, editions 2000 to 2007–2008. The World Economic Forum, the publisher of the report, surveys around 10,000 top management business leaders from sample countries annually. They are asked the question "how stringent is your country's environmental regulation? (1 = lax compared with that of most countries, 7 = among the world's most stringent)". The final country score is then averaged over all surveys. Since the survey is conducted in the early months of each year, the score reflects mostly the previous year's experience. Hence, a country's environmental stringency reported in year *t* is regarded as the measure of environmental stringency of that country in year $t-1$. To construct the measure of environmental laxity, we simply subtract the environmental stringency score from 8, so that the order is reversed preserving the 1 to 7 scale.

Capital abundance: measured by a country's physical capital stock divided by total labor force. To estimate the level of physical capital stock, we follow the perpetual inventory method. Specifically, we set a country *c*'s initial capital stock in year 1995 as $K_{c,1995} = 5 \times (GFCF_{c,1994} + GFCF_{c,1995})$, where *GFCF* is the gross fixed capital formation in constant 2000 U.S. dollar. Assuming the capital stock is depreciated by 7% each year, the capital stock in the following year is calculated as $K_{ct} = 0.93 \times K_{c,t-1} + GFCF_{ct}$. *GFCF* and total labor force are drawn from the World Development Indicators (WDI) 2011.

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[24] For example, we assume that a firm's FDI to chemical industry in China during 2007 is due to the decision made at the beginning of 2007, and that decision is based on information available at the end of 2006, which corresponds to country and industry data in 2006.

Skill abundance: defined as human capital per worker. We construct the measure following Hall and Jones (1999) with Barro and Lee's educational attainment data set (Barro and Lee, 2013).[25] For details, see Hall and Jones (1999). Since educational attainment data is available every 5 years, we linearly interpolate the data for missing years.

Raw material abundance: proxied by a country's land area per worker in the labor force. Land area is drawn from the WDI 2011.

Contract enforcement: proxied by the rule of law indicator from the Worldwide Governance Indicators. For information about the indicator, see Kaufmann et al. (2009).

GDP and GDP per capita: expenditure-side GDP at current purchasing power parities (in billion 2005 U.S. dollar) is drawn from Penn World Table (PWT) 8.0. Population variable in PWT is used to convert GDP into per capita terms.

Market size: proxied by a host country GDP.

Similarity between home (k) and host (c) countries: defined as $sim_{ct} = 1 - s_{ct}^2 - s_{kt}^2$ where $s_{ct} = gdp_{ct}/(gdp_{ct} + gdp_{kt})$, $s_{kt} = gdp_{kt}/(gdp_{ct} + gdp_{kt})$. This measure hits the maximum at one half when two countries are identical in terms of GDP, and declines toward zero as the figures grow further apart from each other.

B.3. Industry characteristics

South Korean industry characteristics are sourced from the Korean Statistical Information Service (KOSIS). Original data is classified by either KSIC Revision 8 or 9.

Pollution intensity: measured by energy intensity, which is the sum of fuel and electricity use scaled by total output. Table B.5 lists the top 10 most and least polluting industries in our measure of pollution intensity, and the list is compared to the ranking of pollution intensity measured by the IPPS.

Physical capital intensity: measured by the real capital stock per worker in an industry. The real capital stock includes the total amount of tangible buildings and structures, machines, equipments, vehicles and other tangible assets. Land asset is not included.

Skill intensity: measured by non-production worker's share out of total employment.

Raw material intensity: measured by the value of raw material inputs per output.

Machinery intensity: measured by the value of machinery per output.

Value added: measured by the value added per output.

Plant-level scale economies: measured by the value of buildings, structures, and land per output.

B.4. Data sources in Fig. 3

Air pollutants (SOx, NOx, CO, PM10): from the National Institute of Environmental Research (NIER, 2008).

Waste water: from the Korean Statistical Information Service (KOSIS).[26]

Toxin: from Pollutant Release and Transfer Registers (PRTR).[27]

Table B.1
List of 50 host countries by RTA.

ASEAN (6)	MERCOSUR (2)	EU (17)	N/A (19)
Cambodia	Argentina	Belgium	Australia
Indonesia	Brazil	Bulgaria	Bangladesh
Malaysia		Czech Republic	Chile
Philippines		Finland	China
Thailand		France	Ecuador
Vietnam		Germany	Egypt
		Hungary	El Salvador
		Ireland	Guatemala
		Italy	Honduras
CIS (3)	NAFTA (3)	Luxembourg	India
Kazakhstan	Canada	Netherlands	Japan
Kyrgyz Republic	Mexico	Poland	Kenya
Russia	United States	Portugal	New Zealand
		Slovak Republic	Nicaragua
		Slovenia	Pakistan
		Sweden	Peru
		United Kingdom	South Africa
			Switzerland
			Turkey

Table B.2
Sample summary statistics.

Data used in	Tables 1, 2, A.1		Table 3		Table 4	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Amount of FDI (in millions 2000 US$)	6.882	38.14	–	–	–	–
Number of new foreign affiliates	–	–	0.351	4.287	–	–
Import (in billions 2000 US$)	–	–	–	–	1.815	12.58
Market size (*mkt*)	7.059	1.721	5.667	1.604	6.360	1.381
Similarity (*sim*)	−1.310	0.583	−1.473	0.869	−1.161	0.527
Environmental laxity (*rlax*)	0.0800	0.377	−0.0451	0.419	−0.139	0.424
Capital abundance (*rkl*)	−1.795	1.555	−1.258	1.396	−0.988	1.384
Skill abundance (*rhl*)	−0.249	0.235	−0.196	0.216	−0.165	0.211
Raw material abundance (*rml*)	1.148	1.246	1.546	1.583	1.518	1.450
Contract enforcement (*rlaw*)	−0.282	0.332	−0.201	0.371	−0.117	0.340
GDP per capita (*rgdppc*)	−1.093	1.109	−0.761	1.098	−0.527	1.014
Pollution intensity (*PI*)	−4.429	0.878	−4.249	0.916	−4.316	0.911
Capital intensity (*KI*)	−3.122	0.844	−3.155	0.800	−3.210	0.770
Skill intensity (*HI*)	−1.218	0.251	−1.236	0.296	−1.238	0.286
Raw material intensity (*MI*)	−0.692	0.218	−0.714	0.236	−0.705	0.212
Machinery intensity (*CI*)	−0.903	0.378	−0.920	0.369	−0.913	0.364
Value added per output (*VA*)	−0.943	0.217	−0.921	0.236	−0.926	0.220
Plant-level scale economies (*SE*)	−1.595	0.424	−1.464	0.462	−1.505	0.431
Host country tariff rates (*Htariff*)	2.155	0.849	2.077	0.876	2.012	0.830
Home country tariff rates (*Ktariff*)	1.993	0.663	1.911	0.882	2.041	0.619
N	3196		44,809		24,786	

Notes: All dependent variables are measured in level, while all explanatory variables are log transformed.

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[25] We also used an alternative measure of skill endowment: a country's skilled worker share of total labor force. For a measure of skilled worker, we used the total number of people aged between 15 and 64 with tertiary education, which came from the International Institute for Applied Systems Analysis & Vienna Institute of Demography (IIASA/VID) educational attainment data set. This data set is available in the World Bank database. The analysis using this measure did not change the results qualitatively.

[26] http://kosis.kr/eng/.

[27] http://ncis.nier.go.kr/prtr/simple/simplepage.do.

Table B.3
Correlation between country and industry characteristics.

Country characteristics	*rlax*	*rkl*	*rhl*	*rml*	*rlaw*	*rgdppc*
Environmental laxity (*rlax*)	1					
Capital abundance (*rkl*)	−0.775	1				
Skill abundance (*rhl*)	−0.694	0.589	1			
Raw material abundance (*rml*)	−0.095	0.019	0.369	1		
Contract ENFORCEMENT (*rlaw*)	−0.909	0.770	0.735	0.165	1	
GDP per capita (*rgdppc*)	−0.837	0.921	0.701	0.153	0.878	1
Industry characteristics	*PI*	*KI*	*HI*	*MI*	*CI*	*VA*
Pollution intensity (*PI*)	1					
Capital intensity (*KI*)	0.481	1				
Skill intensity (*HI*)	−0.249	0.062	1			
Raw material intensity (*MI*)	−0.310	0.133	0.168	1		
Machinery intensity (*CI*)	0.376	0.444	−0.272	0.076	1	
Value added (*VA*)	0.156	−0.157	−0.101	−0.864	−0.077	1

Notes: Correlation coefficients are calculated with the 3196 observations shown in Table 1.

Table B.4
Average Ranking of Environmental Laxity and Factor Abundances.

Ranking	Environmental laxity		Capital/labor		Skill/labor		Raw material/labor	
(Top to bottom)								
1	Kyrgyz Republic	1.705	Luxembourg	2.752	United States	1.128	Australia	181.78
2	Cambodia	1.600	Japan	2.627	Czech Republic	1.128	Canada	127.47
3	Nicaragua	1.558	Switzerland	1.873	New Zealand	1.097	Kazakhstan	83.81
4	Bangladesh	1.541	United States	1.537	Australia	1.068	Russia	53.90
5	Guatemala	1.540	Belgium	1.462	Ireland	1.042	Argentina	37.26
6	Vietnam	1.509	Germany	1.345	Sweden	1.037	New Zealand	31.51
7	Ecuador	1.503	Italy	1.241	Germany	1.037	Finland	27.38
8	Kazakhstan	1.479	France	1.235	Slovak Republic	1.030	Chile	27.33
9	Honduras	1.453	Australia	1.232	Hungary	1.028	Peru	25.23
10	Pakistan	1.452	Netherlands	1.227	Canada	1.021	Brazil	22.51
(Bottom to top)								
1	Germany	0.395	Cambodia	0.013	Guatemala	0.518	Bangladesh	0.460
2	Sweden	0.463	Kyrgyz Republic	0.015	India	0.535	Netherlands	0.965
3	Finland	0.483	Kenya	0.017	Bangladesh	0.546	Japan	1.312
4	Switzerland	0.483	Bangladesh	0.019	Pakistan	0.568	Belgium	1.635
5	Netherlands	0.487	Vietnam	0.027	Vietnam	0.592	India	1.748
6	Luxembourg	0.561	Pakistan	0.034	Nicaragua	0.603	Vietnam	1.831
7	Belgium	0.581	India	0.036	Indonesia	0.609	United Kingdom	1.941
8	New Zealand	0.587	Indonesia	0.056	Egypt	0.610	Germany	2.050
9	Australia	0.624	Nicaragua	0.057	Cambodia	0.641	Philippines	2.106
10	Canada	0.641	Philippines	0.058	Honduras	0.647	El Salvador	2.143

Notes: All values are averaged over the years 1999–2006 and measured in relative terms.

Table B.5
Ranking of pollution intensity.

Ranking	ISIC4	Pollution intensity (our measure)		ISIC4	Pollution intensity (IPPS)	
Top 10 most polluting industries						
1	2394	Cement, lime and plaster	0.196	2394	Cement, lime and plaster	107.121
2	2392	Clay building materials	0.177	2396	Cutting, shaping and finishing of stone	37.670
3	1701	Pulp, paper and paperboard	0.103	2392	Clay building materials	27.742
4	1062	Starches and starch products	0.099	1701	Pulp, paper and paperboard	27.658
5	1313	Finishing of textiles	0.092	1910	Coke oven products	25.681
6	2431	Casting of iron and steel	0.084	1629	articles of cork and plaiting materials	20.994
7	2030	Man-made fibers	0.081	1702	Corrugated paper and paperboard	20.155
8	2011	Basic chemicals	0.077	1920	Refined petroleum products	19.639
9	2393	Other porcelain and ceramic products	0.074	2410	Basic iron and steel	19.163
10	2310	Glass and glass products	0.067	1709	Articles of paper and paperboard	18.439

(*continued on next page*)

Table B.5 (*continued*)

Ranking	ISIC4	Pollution intensity (our measure)		ISIC4	Pollution intensity (IPPS)	
Top 10 least polluting industries						
1	2630	Communication equipment	0.002	1104	Soft drinks	0.010
2	1512	Luggage, handbags and the like	0.003	2680	Magnetic and optical media	0.010
3	2620	Computers and peripheral equipment	0.003	2620	Computers and peripheral equipment	0.013
4	2660	Irradiation, electromedical equipment	0.003	2660	Irradiation, electromedical equipment	0.031
5	2640	Consumer electronics	0.004	2733	Wiring devices	0.057
6	1410	Wearing apparel, except fur apparel	0.004	1393	Carpets and rugs	0.078
7	1200	Tobacco products	0.004	2651	Measuring and control equipment	0.110
8	2815	Ovens, furnaces and furnace burners	0.004	1394	Cordage, rope, twine and netting	0.111
9	3212	Imitation jewelry and related articles	0.004	1391	Knitted and crocheted fabrics	0.112
10	3020	Railway locomotives and rolling stock	0.005	2812	Fluid power equipment	0.129

Notes: All measures are averaged over the years 1999–2006.

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