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# **Environmental impact of foreign versus domestic capital investment in China**

By

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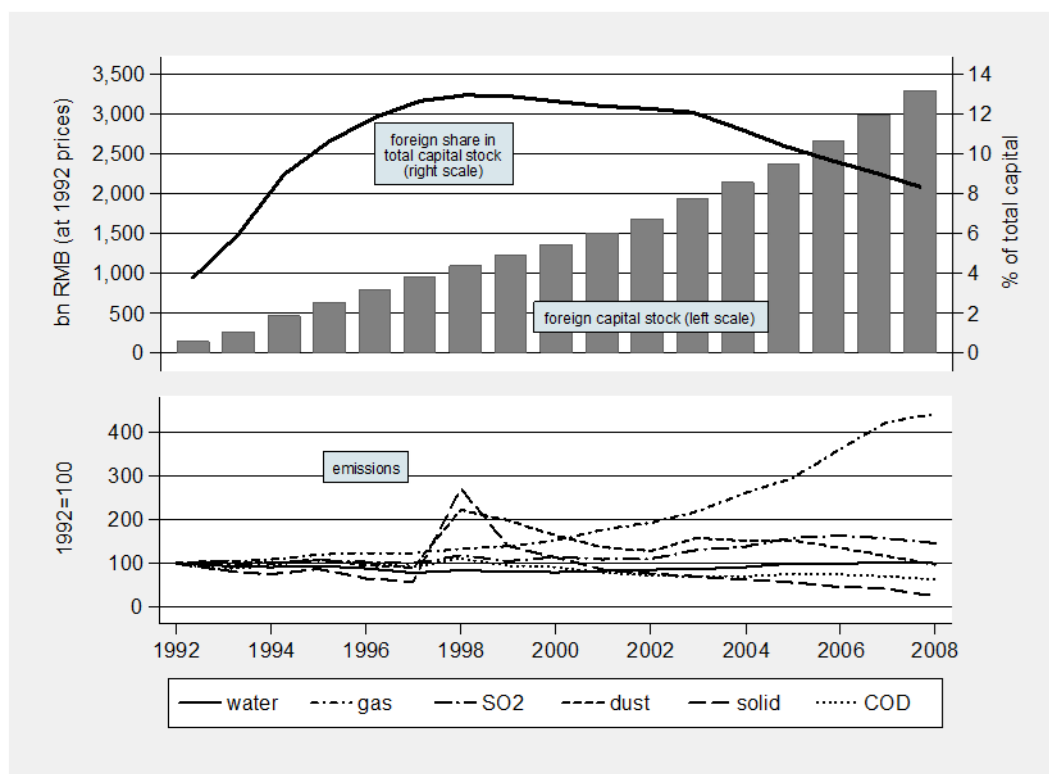
**Abstract:** We compare environmental impacts associated with incoming foreign direct investment versus domestic capital in China. We use aggregate data on Chinese provinces' economic and pollution indicators to explore the effects of the financial origin of fixed capital. Our simultaneous models consider three prime channels through which these effects work: economic scale, sectoral composition, and pollution intensity. Results show that emissions associated with foreign financed capital are lower than with domestically financed capital for some but not all of the considered types of pollution.

**Key words:** Domestic capital, foreign direct investment (FDI), environmental impacts, pollution emission

## 1 Introduction

Since its market reforms began in 1978, China has achieved impressive economic growth, with an average growth rate of 9 per cent since 1978, the highest in the world for that period. China's economic achievement seems to owe much to the adoption of radical initiatives encouraging inward foreign direct investment (Buckley *et al.*, 2007). This became legally possible as a result of the market-oriented economic reforms that commenced in 1978. Deng Xiaoping's call for economic liberalisation triggered further reforms in 1993, during which the Chinese government launched a new round of measures to attract foreign direct investment (FDI). Indeed, FDI accounted for over 10 per cent of China's gross fixed capital formation during most of the 1990s (UNCTAD, 2011a) and although this share later declined due to soaring investment from domestic sources, China has been the largest FDI recipient among developing countries since 1992 (OECD and EIRIS, 2011). According to the World Investment Report 2011 (UNCTAD 2011), FDI inflows into China amounted to 106 bn US dollars in 2010, representing 4.1 per cent of Chinese gross fixed capital formation. By the end of 2010, more than 450 of the world's top 500 multinational enterprises (MNE) had invested in China.

The upper panel of figure 1 illustrates the development of the foreign financed capital stock during the period considered in this study.<sup>1</sup> This stock grew continuously at an average annual rate exceeding 20 per cent. The foreign financed share of the total value of fixed capital stock increased to 13 per cent in 1998, and then decreased as investments from Chinese capital grew even faster.



SOURCE: NBS 2009; NBS CHINA ENVIRONMENT STATISTICAL YEARBOOK, VARIOUS ISSUES

FIGURE 1. FOREIGN FINANCED FIXED CAPITAL AND INDUSTRIAL POLLUTION INDICATORS  
IN CHINA, 1992-2008

The multinational enterprises accounting for most incoming FDI have introduced new methods of production and management and in this way have affected growth, employment, technology and other economic and social parameters in China, as well as in other host countries; this has led researchers to study the effects of FDI. A

<sup>1</sup> For details on the calculation of these figures, based on period FDI, see section 3.1.

number of studies have analysed the environmental effects of FDI in host countries, as environmental deterioration during periods of surging growth has raised worries about the harmful pollution effects of FDI.

The lower panel in figure 1 illustrates the dynamics of six key indicators of environmental pollution by the industrial sector during the 17 years covered by this study<sup>2</sup>. The only group of pollutants exhibiting a continuous increase was emissions of industrial waste gas, which has more than quadrupled. These pollutants include emitted air (or other gas) loaded with dust or soot and emissions of pure gas types like SO<sub>2</sub>, NO, or NO<sub>2</sub>. One particular gas, industrial sulphur dioxide (SO<sub>2</sub>), also followed a clear upward trend; it is a prime pollutant emitted by burning fossil fuels which harms human health, can contribute to soil acidification and is also an indicator of Greenhouse Gas emissions. The other pollution indicators have fluctuated during the considered period, with three forms of industrial pollution reaching pronounced peaks in 1998 and levelling off in subsequent years: solid waste, industrial dust, and pollution of surface water with organic matter (as represented by chemical oxygen demand (COD)). Although these dynamics approximately parallel the development of the foreign share in fixed capital, visual inspection at this national aggregate level does not suggest any obvious links between investment variables in the upper panel and pollution variables in the lower panel of the graph.

Some concern with the environmental impacts of FDI reflects the negative effects derived from the “pollution haven” hypothesis (Dean et.al, 2009; Zhang and Fu, 2008; Di, 2007), which suggests that FDI transfers pollution-intensive industries into developing countries to evade strict environmental regulations and concerns in their home countries. Furthermore, given that high pollution taxes could repel foreign investment (Markusen *et al.*, 1995), it was claimed that host country governments

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<sup>2</sup> The pollution emission indices displayed in figure 1 refer to absolute quantities emitted, taken from the China Environmental Statistical Yearbook (1991-2009). For details see table 1 in section 3.

were competing with each other in lowering environmental standards in order to attract FDI, a phenomenon described as “race to the bottom” (Dua and Esty, 1997; Esty and Geradin, 1997). According to these papers, most of the FDI attracted by developing countries comes at the cost of serious pollution. However, other papers, particularly from the field of enterprise management, show that due to advanced environmental management and technology, the environmental performance of MNEs is often better than that of local enterprises in the same business (Jenkins, 1999; Wang and Jin, 2002). The overall environmental effect of fostering FDI is indeterminate if MNEs concentrate on pollution intensive industries, but also have better environmental management. MNEs may have superior environmental performance but their actions could lead to greater pollution by contributing to overall expansion of the economy and/or shifting the economy towards a pollution-intensive industry structure.

More recent papers on the pollution effects of FDI were motivated by the idea of an Environmental Kuznets Curve (EKC), which describes the relationship between economic development and pollution (Cole *et al.*, 1997; Wheeler, 2001; De Lucia, 2003; Haisheng *et al.*, 2005; Khalil and Inam, 2006; Liang, 2006; Zheng *et al.*, 2010; Cole *et al.*, 2011). These studies, which apply a wide range of empirical approaches, do not arrive at consistent results. Some of them conclude that FDI tends to decrease pollution but others insist it does not. Copeland and Taylor (2004) criticise the concept of a unique curve representing the growth-pollution-relationship, arguing that different types of growth (differing in terms of the main drivers) are bound to have fundamentally different environmental effects.

Governments’ positions regarding the extent to which their countries should foster or constrain foreign investors relative to domestic investment should account for the aspect of environmental effects of FDI. Studies supporting such decisions have to consider that the environmental effects of FDI can work through various channels. In their works on economic development and international trade, Copeland and Taylor

(1994, 1995, 2001, 2004, 2005) attribute pollution effects to three major channels: economic scale, industrial structure, and technology, with the 'technology' channel representing environmental efficiency and being strongly influenced by governmental regulation.

Cole and Elliott (2005) study the determinants of a variety of pollutants in the UK, and consider a number of industrial and societal characteristics that are likely to affect demand for or/and supply of environmental quality and estimate their impacts in single equation models. Industry's expenditure on fixed capital scaled by value added, i.e. a measure of capital intensity (or more precisely the vintage of production processes) is found to have a pollution-reducing effect but a distinction between foreign and domestically financed capital is not made. Cole *et al.* (2008) also focus on the demand for and supply of environmental quality using data from China, and find industry's emissions to be a positive function of energy use and human capital intensity, and a negative function of productivity and R&D expenditure. Cole *et al.* (2011) address links between the origin of fixed capital and pollution by analysing data for 112 Chinese cities between 2001-2004 and focus on the shares in GDP of firms owned by investors from three distinct regional origins. They find that several types of pollution are lower in cities with relatively high output shares of firms capitalised from Hong Kong, Taiwan, or Macao, while these pollution levels are higher in cities with high output shares of investments from other domestic or foreign origins. The employed specification is a reduced form, accounting only for – aside from the output shares of firms from different origins – (linear and squared) income levels as potential drivers of pollution. However, it is possible that other variables may influence pollution levels, which would mean that it may not be justified to interpret these impacts as origin effects alone.

Studies published by He (2006, 2008) also analyse the pollution effects of FDI in China. For SO<sub>2</sub> emissions in Chinese provinces (He, 2006) and for total suspended particles (TSP) and SO<sub>2</sub> emissions in 80 Chinese cities (He, 2008), she estimates

simultaneous equation models accounting for the three channels mentioned above, i.e. scale, industrial composition, and technology (Copeland and Taylor, 2004). She finds mostly positive yet small effects of FDI on pollution. However, these results do not identify the relative advantage (or disadvantage) in terms of pollution of foreign financed capital compared to domestically financed capital. Knowledge regarding such an effect, which could support politicians in deciding whether FDI should be encouraged, is not derivable from this work.

This is the aspect we address in our study. Particularly, we assess to what extent the financial origin of fixed capital affects emissions of six types of pollutants. To compare the environmental effects of foreign and domestically financed capital, we specify simultaneous equation systems considering scale, composition and pollution density effects of both kinds of capital following Copeland and Taylor. The functional form used for estimating the effects is particularly suitable for comparing the effects of equal sized changes in foreign or domestically financed fixed capital. We derive a pollution difference index to compare the pollution effects of the two origins of capital.

The remainder of the paper is organised as follows. In the next section, we explain the theoretical framework. Section 3 presents the various sources of data used in the paper, including information about proxy variables used to reflect qualitative provincial characteristics. The econometric approach and empirical results are described and discussed in section 4, followed by conclusions in section 5.

## 2 Model

To fill the gap in the literature on the FDI-environment linkage, we compare the impact of foreign and domestic investment on pollution. We assess this origin effect econometrically by examining the extent to which variation in pollution emissions over provinces and years can be attributed to variations in the stock of foreign and domestically financed fixed capital,  $C_f$  and  $C_d$ , respectively. Comparing the estimated



impact parameters of  $C_f$  and  $C_d$ , respectively, reflects the origin effect, providing there are no other important determinants of pollution  $P$ . We account for the impact of such determinants by including a vector  $\xi$  of control variables:<sup>3</sup>

$$P = P(C_f, C_d, \xi) \quad (1)$$

In our model a stylised economy comprises a polluting industrial sector and a non-polluting, non-industrial sector. Following Copeland and Taylor (1994), the total emission quantity  $P$  of a pollutant can then be described as being determined by three factors: the economy's output level or scale,  $Y$ ; its sectoral composition  $Comp$  (in particular the share in output of the industrial sector, regarded as the primarily pollution-intensive one); and the pollution-output ratio in the industrial sector, i.e. its pollution intensity  $PI$ , which is determined by technology, such that:

$$P = Y * Comp * PI \quad (2)$$

Analogous to Copeland and Taylor's analysis, which focuses on the impacts of exports on pollution, we assume that each of the three factors is influenced in a distinct way by the amounts of foreign and domestic capital. The general form (1) can hence be represented as:

$$P = Y(C_f, C_d, \xi_Y) * Comp(C_f, C_d, \xi_{comp}) * PI(C_f, C_d, \xi_{PI}) \quad \text{with } \xi_Y \cup \xi_{comp} \cup \xi_{PI} = \xi \quad (3)$$

meaning that the impact of foreign and domestic capital on total pollution is completely determined by their respective impacts on scale, composition, and pollution intensity. We now present the specifications we use to reflect these three channels, through which fixed capital impacts pollution.

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<sup>3</sup> We assume that further determinants which are not included in our model are not correlated with the variables that are included.

## 2.1 Economic scale

In our stylised model each province has the same time-invariant production function, which supposes that the coefficients are the same over provinces and years. We assume an aggregate production function similar (but not identical) to the Cobb-Douglas type:<sup>4</sup>

$$Y = \alpha_0 e^{\alpha_f C_f} e^{\alpha_d C_d} L^{\alpha_L} E^{\alpha_E} \quad (4)$$

with labour ( $L$ ) and capital (both  $C_f$  and  $C_d$ ) being traditional inputs in production, and education ( $E$ ) included as an input as suggested by the new growth theory to capture the growth impact of human capital (Barro, 1991; Barro and Lee, 2001). Distinct effects of domestic and foreign capital are allowed for because foreign investors may typically set up facilities that employ different technologies than domestic investors. Moreover, inward FDI may foster economic growth in a host country through technology spill over to domestic capital and by opening new export markets (Ram and Zhang, 2002; Johnson, 2006). Our parameterisation implies that the coefficients  $\alpha_f$  and  $\alpha_d$  indicate percentage changes of output associated with fixed-size (one-unit) changes of the two types of capital,  $C_f$  and  $C_d$ , respectively.<sup>5</sup> Analogous specifications are used in the equations in the remainder of this section.

## 2.2 Composition Effect

The pollutants we consider in our study are mainly emitted by the industrial sector. To

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<sup>4</sup> In the limited domain of variable values relevant in the present study, we find this computationally convenient functional form acceptable.

<sup>5</sup> We hence assume constant coefficients  $\partial Y/Y / \partial C$  rather than the constant elasticities

$\partial Y/Y / \partial C/C$  implied by the Cobb-Douglas form. Since  $C_f$  and  $C_d$  have very different orders of magnitude, responses to percentage changes of both types of capital (as reflected by elasticities) would impede our objective to compare effects between origins.

model the share of the industrial sector in total output of an economy, prime determinants to consider are capital ( $C$ ) and labour ( $L$ ) endowments because industry has, on average, a specifically high capital-labour ratio, i.e., it requires relatively high availability of capital. We allow foreign and domestically financed capital to have distinct effects on the relative size of the industrial sector because relative factor scarcities, as well as the regulative environment, may strongly differ between investor and host countries. For instance, investors from foreign countries with restrictive industrial laws may have a stronger focus on the industrial sector of the target country than domestic investors have. Others may focus on agriculture if farm land in their country is particularly scarce, or on the services sector if labour is more expensive in their home country. Income level has proven to be another important driver of the share of industry in a county. For example, Wang and Jin (2002) describe the evolution of the sectoral structure of an economy with growing per capita income ( $Y/pop$ ). During early stages of the development of income, demand for manufactured goods increases relative to primary sector produce, particularly from agriculture. In later stages of development the importance of industry decreases relative to the service sector. To be able to capture such potential nonlinear effects, we include per capita income, as well as its square in our modified Cobb-Douglas model of the sectoral composition:

$$Comp = \beta_0 e^{\beta_f C_f} e^{\beta_d C_d} L^{\beta_L} \left( \frac{Y}{POP} \right)^{\beta_Y} \left( \left( \frac{Y}{POP} \right)^2 \right)^{\beta_{Ysq}} \quad (5)$$

## 2.3 Pollution Intensity

Pollution intensity measures the quantity of emissions per unit of industrial output. The term suggests that environmental quality is to be viewed as a production factor.

Copeland and Taylor (2004) derive the quantity and the price of pollution emission as an equilibrium solution equating industry's demand for and the society's supply of environmental quality. In their stylised model, industry's pollution demand

corresponds to technology levels and depends on the industry's capital and labour endowment, as well as on product prices as exogenous determinants. Society's environmental quality supply is modelled to depend on society's rate of substitution between income and environmental quality, which is in turn assumed to be primarily determined by the population's income level. Furthermore, population density in an area is assumed to exert pressure on the government to make regulation stricter; so it can be regarded as a determinant of the strictness of regulation (Panayotou, 1997; Co *et al.*, 2008).

We employ a reduced form specification for pollution intensity, combining determinants of both supply and demand in a modified Cobb-Douglas type function:

$$PI = \gamma_0 e^{\gamma_f C_f} e^{\gamma_d C_d} T_{env}^{\gamma_e} T_{gen}^{\gamma_g} ER^{\gamma_s} Pdens^{\gamma_p} \quad (6)$$

The impact of fixed capital as an aggregate on the industrial sector's pollution intensity is not theoretically predictable. Depending on whether output is expanded by adding new production facilities, labour is substituted, or outdated machines are replaced by technically advanced successors, the effects are likely to vary in scale and in sign. Hence, different effects of foreign and domestically financed fixed capital, respectively, are again allowed for because technical and environmental standards in investors' home countries are assumed to be embodied in the layout and technical standards of their production facilities, even if installed abroad. With regard to foreign capital, aside from direct effects there may also be spill over effects on the technology and management practices of competing domestic firms, as well as on upstream and downstream industries (Javorcik, 2004).

In addition to the volume of fixed capital, we also include the state of technological development as a potential determinant of pollution intensity. We distinguish between general technology ( $T_{gen}$ ) on the one hand, which we reflect by R&D efforts (measured by patent applications), and environmental technology ( $T_{env}$ ) on the other hand, which is measured by public investments into environmental R&D. While environmental technology decreases pollution emissions definitely, the sign of environmental effects of the prevailing level of productive technology has sometimes been found to be indeterminate (e.g. Yang, 2010).

Finally, we include a control variable to account for the strictness of environmental regulation,  $ER$ , a measure related to the society's supply of pollution (rights). At present, in China there are 7 national environmental laws and 29 laws related to environmental protection in effect, but the strictness of enforcement has varied considerably over time, as well as between provinces because of differences in administrative structures and effectiveness. The strictness of environmental regulation can be regarded as a price of pollution from the perspective of industry and is hence included in the model as a determinant of pollution.

## 2.4 Interdependencies

Among the three pollution channels presented, we see that scale  $Y$  is endogenous to composition  $Comp$ . Furthermore, we have to consider that the determinants, the impact of which we intend to analyse, i.e. foreign and domestically financed capital, must be assumed themselves to be influenced by economic scale mainly because growth encourages investment. Investment, growth, composition, and pollution intensity are hence determined simultaneously, which needs to be accounted for by using a model comprising interdependent equations.

Navaretti *et al.* (2004) conclude from their study that the availability of cheap factors of production and a large market are likely to raise the potential profitability of investment and can hence attract FDI. Accordingly, we model foreign financed capital  $C_f$  as depending on two cost factors, the wage level,  $w$ , and the strictness of environmental regulation  $ER$ , as well as on two factors related to the quality of the business environment: quality of the technical infrastructure  $IS$ , which in our empirical model is proxied by the length of highways and railway tracks per square kilometre land area; and per capita income level in the target region as a measure of the level of development. We consider a static approximation of capital formation an acceptable specification for this study.

We model domestically financed capital  $C_d$  using a specification with per capita income and foreign direct investment as the two sole arguments. FDI is likely to

influence domestic investment by crowding out (Backer and Sleuwaegen, 2002), by generating spill over effects, and/or by attracting domestic investment in upstream or downstream industries (Tang *et al.*, 2008).

To summarise, the channels of impact from FDI on pollution emission are shown in figure 2. Our full simultaneous model comprises the following five equations:

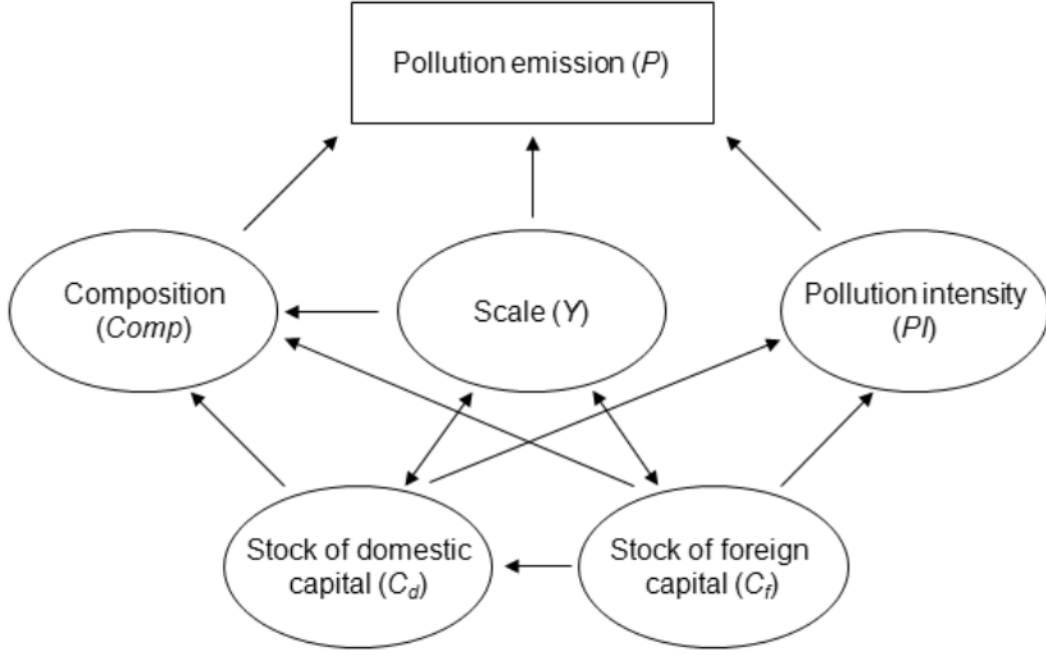


FIGURE 2. IMPACT CHANNELS BETWEEN CAPITAL AND POLLUTION EMISSIONS

$$\begin{aligned}
 Y &= \alpha_0 e^{\alpha_f C_f} e^{\alpha_d C_d} L^{\alpha_L} E^{\alpha_E} \\
 Comp &= \beta_0 e^{\beta_f C_f} e^{\beta_d C_d} L^{\beta_L} \left( \frac{Y}{POP} \right)^{\beta_Y} \left( \left( \frac{Y}{POP} \right)^2 \right)^{\beta_{Ysq}} \\
 PI &= \gamma_0 e^{\gamma_f C_f} e^{\gamma_d C_d} T_{env}^{\gamma_e} T_{gen}^{\gamma_g} ER^{\gamma_S} Pdens^{\gamma_P} \\
 C_f &= \delta_0 + \delta_Y \ln \frac{Y}{POP} + \delta_w \ln w + \delta_S \ln ER + \delta_I \ln IS \\
 C_d &= \phi_0 + \phi_f C_f + \phi_Y \ln \frac{Y}{POP}
 \end{aligned} \tag{7}$$

Before moving to the empirical counterpart of this structural model in section 4, we

now describe the data set used.

### **3 Data**

In our empirical analysis we estimate parameters reflecting the impact of foreign and domestically financed fixed capital and various other economic factors on the environment, in particular on pollution emission. We use annual data from 1992 to 2008 at the regional level covering three administrative cities (Beijing, Tianjin, Shanghai) and 25 provinces<sup>6</sup>. Definitions and descriptive statistics of the variables used in our estimation are presented in table 1.

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<sup>6</sup> Tibet and Hainan were excluded from our analysis because most of their relevant data are either not available or zero during the time period examined. Data for Hong Kong, Macao, and Taiwan were collected in ways not comparable to the rest of the regional entities, so they were also excluded. The Administrative City of Chongqing, which was part of Sichuan Province until 1996, was established in 1997. We add the data of Chongqing with Sichuan to obtain a regional base consistent over time.

Table 1: Descriptive statistics of the variables used

Name	Description	Unit / definition	Mean	Std. dev.	Min	Max
<i>Indicators of industrial pollution (relative to volume of industrial output)<sup>#</sup></i>						
PI-wat er	waste water emissions / indust. output	Tons / 10,000 RMB <sup>#</sup>	110.4	87.7	6.7	626.7
PI-gas	gas emissions / indust. output	m3 / RMB <sup>#</sup>	8.46	4.96	1.75	26.93
PI-SO 2	SO <sub>2</sub> emissions / indust. output	Tons / 10,000 RMB <sup>#</sup>	0.099	0.104	0.005	1.076
PI-dus t	dust emissions / indust. output	Tons / 100 mio. RMB <sup>#</sup>	494.5	440.6	2.5	2652.1
PI-soli d	solid waste formation / indust. output	Tons / 10,000 RMB	0.239	0.556	0.0	7.148
PI-CO D	indust. COD emissions / indust. output	Tons /100 million RMB <sup>#</sup>	380.3	444.9	4.0	4764.6



Table 1: Descriptive statistics of the variables used

Name	Description	Unit / definition	Mean	Std. dev.	Min	Max
<i>Economic indicators</i>						
$Y$	GDP (volume)	100 million RMB <sup>#</sup>	2797.1	3006.7	83.1	20156
$C_f$	Stock of foreign financed fixed capital	100,000 RMB <sup>#</sup>	0.528	0.909	0.00	5.68
$C_d$	Stock of domestic capital	100,000 RMB <sup>#</sup>	4.59	5.01	0.19	34.35
$L$	Labor force	No. of people working, 10,000	2394	1625	226	8010
$E$	Education	Share of secondary students in population [%]	6.0	2.1	0.17	10.0
$ER$	Environmental regulation intensity	number of environmental agency staff / 10,000 inhabitants	1.10	0.49	0.30	3.24
$Pdens$	Population density	residents / 100 km <sup>2</sup>	3.66	4.04	0.06	21.94
$Comp$	Share of indust. output in total output	Ratio	0.39	0.07	0.21	0.57
$\frac{Y}{POP}$	Annual per capita GDP	RMB	6861	6356	1034	41289
$w$	Average wage rate	RMB per laborer and year	7300	4792	2154	31805
$T_{gen}$	General technology level	Number of patent applications / 10,000 laborers, prec. year <sup>*</sup>	2.7	5.3	0	45
$T_{env}$	Environmental technology level	Govt. spending for environmental R&D, prec. year, 10,000 RMB <sup>§</sup>	0.41	0.53	0	3.96
$IS$	Density of highways and railways	Km / km <sup>2</sup>	0.411	0.340	0.017	2.547

Notes:<sup>#</sup> at 1992 prices.

\* Unavailable values for 1991-1993 were imputed by extrapolation using average growth rates.

§ Unavailable values for 1991 were imputed by extrapolation using average growth rates.

We reflect the industrial sector's pollution emission by six pollution indicators. Four of these are measures of total quantities emitted irrespective of chemical composition but distinct by physical form: polluted waste water and solid wastes, each measured by weight, as well as m<sup>3</sup> of polluting gas (e.g. air or other gas loaded with dust or soot, as well as gas types such as SO<sub>2</sub>, NO<sub>x</sub>, or CO). As a measure of the pollution of industrial waste water with organic material, we consider chemical oxygen demand

(COD). This type of pollution is heavily discharged, e.g. by branches of the food industry and the paper and pulp industry. Finally, we separately consider two pollutants from the gas group: quantities of sulphur dioxide (SO<sub>2</sub>) and industrial dust, each measured in tons. Strong recent increases of both pollutants have been particularly problematic with regard to human health hazards, and their incidence is highly correlated with that of other pollutants. Other indicators, aside from the ones considered in this study, would have been relevant for describing the Chinese environmental situation. However, the six pollution indicators are most relevant for the industrial sector, and continuous time series at the provincial level are available. The data were taken from China's Statistical Yearbooks for Environment (1993 to 2009 issues). The figures were compiled by provincial offices of the Ministry of Environmental Protection from surveys among key industrial enterprises and estimates for non-key enterprises, respectively. This is the most comprehensive data source available. The pollution intensities  $PI_{water}$ ,  $PI_{gas}$ ,  $PI_{SO2}$ ,  $PI_{dust}$ ,  $PI_{solid}$ , and  $PI_{COD}$  were computed by dividing pollution emission by the value of industrial output in 1992 prices, i.e. by the volume of industrial output.

Data on economic characteristics were taken from the publication titled "60 Years of New China (1949-2008)" (NBS 2009), which combines long time series of provincial level information from various other official Statistical Yearbooks.

We approximate the value of the stock of fixed capital  $C$  from annual data on current investment  $I$  using the perpetual inventory method.<sup>7</sup> Following Zhang *et al.* (2004), we assume that the capital stock in 1951, the first year for which investment data are available, was worth 10 times the investment of that year ( $C_{1951} = 10 I_{1951}$ ) and that capital depreciated at the constant annual rate of 9.6 per cent provided by Zhang *et al.*

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<sup>7</sup> Data on foreign investment, available in terms of USD, were converted to RMB by annual reference exchange rates (NBS 2010). Current investment figures for both total investment and FDI were converted to real terms (1992 prices) using the retail price index (NBS 2009).

Capital in any year  $t > 1951$  is hence approximated as  $C_t = (1 - 0.096)C_{t-1} + I_t$ . FDI was permitted in China only from 1978 onwards, so no assumption on foreign financed starting capital was necessary, and FDI figures were used to approximate the value of the foreign financed capital stock, again by the perpetual inventory method. The value of the domestic capital stock  $C_d$  was derived by deducting foreign capital  $C_f$  from total capital  $C$ .

The share of industry in total output ( $Comp$ ) is represented as the combined shares in GDP of the manufacturing, mining, and utilities sectors.

To represent the level of education ( $E$ ) in a province, we did not have annual information on the distribution of education levels attained by the population. Instead, we used the share of the total population attending secondary school in a given year as a proxy of the general educational level. Although variations in the population's age profile, and of school attendance over time and between provinces are likely to affect the precision of this measure, we found it acceptable as the best proxy available in annual province level data.

Our equation modelling the determination of pollution intensity requires two variables reflecting the technological advance of a region, one for general technology ( $T_{gen}$ ) and one for environmental technology ( $T_{env}$ ). We use the preceding year's number of patent applications in the province relative to its labour force as a measure for innovative spirit and innovative efforts made. This is likely to be highly correlated with general technological innovation. The state of environmental technology is proxied by the preceding years' share in industrial GDP of government expenditure for environmental research and development.

The effective strictness of environmental regulation ( $ER$ ) is likely to be a direct determinant of pollution intensity. With more staff in environmental administration, more attention on pollution is paid by the government. So we use the number of environmental agency staff implementing and enforcing environmental law relative to

the province's population to represent the strictness of environmental regulation.

Finally, as a measure for the available physical infrastructure (*IS*), we use the density of the road and railroad network.

## 4 Empirical implementation and results

### 4.1 Estimation strategy and model diagnostics

For each of the six considered types of pollutant we estimate a system of five equations equivalent to (7)<sup>8</sup>, including 5 endogenous variables. Simultaneity implies the endogeneity of some regressors, which renders OLS a biased estimator. According to the order and rank condition, each equation is over-identified, which allows us to estimate the system by 3SLS. This avoids endogeneity bias and improves efficiency by accounting for correlation of the error terms across equations. We employ a fixed effects specification by introducing a dummy variable for each but one province to account for the panel structure of the data. This helps preventing estimation bias due to heteroskedastic error terms. To mitigate estimation bias, which could arise if the impact of any excluded time-variant determinants were erroneously attributed to fixed capital (and other model variables), we include a linear trend variable ("year") as a simple approach.

We now turn to our estimation results. For an assessment of the explanatory power of our five-equation interdependent model we present several measures in appendix table A1. The R-squared values of individual equations indicate the share of explained variation in total variation of the respective endogenous variable. R-squared values around 0.5 for the composition equation in all models and values of 0.8 or higher for all the remaining equations (see column "R<sup>2</sup>") suggest an acceptable fit.  $\chi^2$  tests

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<sup>8</sup> Practically, we used natural logs of all variables except  $C_f$  and  $C_d$ , and we estimated linear equivalents of the first three equations (see section 2.1, particularly footnote 4 for details).

indicate that all equations outperform the respective constant-only specification (columns  $\chi^2$  and P). Wald tests of the joint hypotheses that the coefficients of the province dummies are zero in all equations justify our choice of a fixed effect specification for all models (not reported). Furthermore, we computed predicted values of total pollution for the six types of emissions substituting predicted values of the model equations in equation (3). The correlation of predicted and observed values (table A1 b) provides a measure of the share of explained variation in total variation. Its values range from 0.74 for the solid waste model, to 0.90 for the waste water model, which indicates a good fit. We compare this with the fit of two simplistic alternative models. The model “OLS” is a linear regression of pollution emissions on just the share of foreign capital in total capital and the level of total capital; its fit is considerably lower than the one of our simultaneous model. “OLS2” is more comparable with our model because it contains as regressors the entire set of exogenous variables from our model, including the trend variable and province dummies. The correlation of predicted and observed pollution is higher for this model (between 0.77 and 0.96) than it is for our interdependent model. This is because parameter estimation in the interdependent model imposes restrictions that are motivated by theory or account for statistical properties. However, while we lack a formal test to compare our (non-nested) model with the OLS2 model, we find that the fit differences are small enough to make further interpretation of our estimated coefficients worthwhile.

Tables A2 to A6 in the appendix report our parameter estimates; the tables contain one column for each model, i.e. for each type of pollution.<sup>9</sup> In the pollution intensity equation (table A4) the lhs variable, *PI*, is different for each pollution type; in the other equations (tables A2, A3, A5, and A6) lhs and rhs variables are the same for

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<sup>9</sup> We report estimation results for the variables in model (7) and the trend variable. Estimates for the 28 province dummies are not included to save space, but are available from the authors upon request.

each model, and differences between columns are small. These differences are due to sampling variance in the pollution data and can be regarded as simultaneity effects ‘induced’ by the *PI* equation. The specification test of Hausman (1978) proves orthogonality conditions of the instruments used for the endogenous variables at the equation level. This supports our assumptions of endogeneity ( $C_f$  and  $C_d$  in the *Y*-, *Comp*-, and *PI*-equations as well as *Y* in the *Comp*-equation) and hence the estimation using an instrument variable model.

For 70 per cent of the coefficients, estimated tests of the null hypothesis that the parameter equals zero were rejected at the 10 per cent level, and most of them show the signs expected according to the reasoning of section 2.

## 4.2 Capital origin effects on pollution

We are particularly interested in the effect of the origin of investments in fixed capital on different types of pollution. We show in appendix B how the effects of the two types of capital on pollution and its “channels” can be expressed in terms of the estimated parameters.<sup>10</sup> Table 2 presents these effects in columns (1) to (8); specifically, columns (1) to (4) for foreign, and (5) to (8) for domestic capital. We provide an example of their interpretation from the first row of the table, which presents coefficients for the pollutant type ‘waste water’. The value of 0.108 in column (1) indicates that an increase of the stock of foreign capital  $C_f$  by one unit, i.e. by 100 000 RMB, is typically associated with an increase of the scale (or output) *Y* of a province’s economy by eleven (10.8) per cent. The value 0.017 in Column (4), though not statistically significant, indicates that a one unit increase of  $C_f$  increases the total waste water pollution (quantity in  $m^3$ ) by two (1.7) per cent.<sup>11</sup> To assess its

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<sup>10</sup> Since foreign capital is regarded as a determinant of domestic capital (crowding out or crowding in effects) the formulae for the impact of  $C_f$  consider distinct direct and an indirect effects.

<sup>11</sup> As derived in appendix B our specification allows us to compute the total pollution effects

statistical significance we use standard errors approximated by the delta method (Greene, 2008: 68). Capital from both origins increases the scale of the economy; the effect is around 11 per cent for an increase in foreign capital by 100 000 RMB, and 5 per cent for the same increase in domestic capital. This indicates a strong productivity advance on the average of foreign financed firms, which can be due to differences in technology, management, and marketing, but also to differences in the industrial sectors that typically attract foreign and domestic capital. Also, foreign investment may trigger domestic investment, e.g. in related industries. Strong stimuli to economic growth by foreign investment through complementing and further encouraging domestic investment in China have been found by several authors (e.g. Tang *et al.*, 2008).

Columns (9) to (12) express the percentage difference of foreign over domestic capital effects. Positive values indicate that foreign capital has stronger positive (or weaker negative) impacts on scale, composition, pollution intensity, and total pollution than domestic capital, and vice versa.<sup>12</sup> Hence, the positive sign of the figure 54.8 in the first row indicates a superiority of foreign capital in terms of the scale effect. This superiority (0.108-0.049) amounts to 55 per cent of the 11 per cent (0.108) effect on scale of foreign capital. As output growth increases emissions, the pollution effect of the scale channel is stronger for foreign investment than it is for domestic sources. Investment of both foreign and domestic capital changes the sectoral composition of the economy towards industrial sectors, as indicated by positive signs in columns (2)

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represented in equation (3) as the sum of the respective scale-, composition-, and pollution intensity effects, each based on parameters estimated from (7); from the 4<sup>th</sup> and 5<sup>th</sup> equation in (7) and linear equivalents of the first three equations, to be exact.

<sup>12</sup> We arrived at this specification for our indicator (choosing from a number of potential candidates with different pros and cons) because we found numerical values and signs intuitively interpretable in the best way possible.

and (6), and the impact of foreign capital is weaker (between 0.6-4.6 per cent) than that of domestic capital (between 5.6-6.9 per cent). According to our stylised model following Copeland and Taylor (2004), the industrial sector is the one emitting pollution, so foreign investment is associated with less pollution (from changing the sectoral structure) than domestic investment is.

Capital of both domestic and foreign origin significantly decreases pollution intensity, the emitted quantities per unit of industrial output, for all pollutants considered except waste gas (columns (3) and (7)). The total (pollution reducing) impact of foreign capital by far exceeds that of domestic capital. For every 100 000 RMB of foreign capital, emissions per RMB of industrial output decreased to an extent between 12 per cent for waste water and 72 per cent for industrial dust. On the other hand, the effects of domestic capital on the pollution intensity vary from 3.4 per cent for waste water to 19 per cent for solid waste. The difference indicator for the pollution intensity effect (column (11)) is significantly negative and large for all pollutants except waste gas. Foreign investment is associated with lower pollution intensity than domestic investment for all pollution indicators except waste gas.

In section 1 we discussed the pollution haven hypothesis, which suggests that developing and transition countries contract pollution-intensive industries, and this is sometimes criticised as neo-colonialist behaviour of developed investor countries. Formally testing the hypothesis would require examination of the domestic industrial structure and outward foreign investment of developed countries. However, from the Chinese perspective, our study shows that for most of the pollutants considered, the foreign financed facilities are associated with lower emissions than domestic investment. This confirms results based on firm-level survey data, such as Wang and Jin (2002), who regard foreign financed firms to be cleaner than local enterprises. In general, China does not have separate environmental standards for foreign investment, although some restricting clauses concerning foreign investors' environmental behaviour can be found in a number of national environmental and industrial laws and



regulations (Xian *et al.*, 1999).

Regarding the total pollution effect, the differences between the effects of  $C_f$  and  $C_d$  (column (12)) are significantly negative for SO<sub>2</sub>, dust, solid waste, and COD. These values imply that for equal amounts of investment, foreign capital has been better for the environment than domestic capital. The order of magnitude of the difference is between 86 per cent of the effect of  $C_f$  for solid waste and 168 per cent for SO<sub>2</sub>. With regard to emissions of waste gas, a pollution increase through foreign capital exceeds the pollution increase through domestic capital so that the value of the difference indicator is positive. This suggests that for this type of pollutant, domestic investment has been environmentally better than foreign investment. However, although the total effects themselves are statistically significant, their difference is not: such inferiority of foreign investment in terms of waste gas is not inferentially supported. Also for waste water no statistically significant result could be established.

Finally, we turn to the estimated coefficients of our linear trend variable. They are significantly positive, around 0.09 in the scale equation of each model. This indicates autonomous growth, i.e. growth in excess of what is explained by changes in capital, labour, and the educational level, of 9 per cent. This magnitude raises concerns because it almost reaches the average annual growth rate in China during the observation period. It may hint at remaining problems in our model specification which may be too restrictive to capture the regressors' true effects. Further significant trend coefficients indicating negative trends were estimated for pollution intensity (between -0.25 for solid waste and -0.03 for gas), and for the stock of domestic capital (around -1.3).

## 5 Conclusions

We used provincial data on Chinese economic and pollution indicators to examine the effects of domestic and foreign investments on six measures of environmental

pollution. Based on a simultaneous model considering three prime channels through which capital influences pollution, we compute difference indicators to highlight the origin effect for fixed capital. Results show that for four major types of industrial pollution ( $\text{SO}_2$ , dust, solid waste, and COD), foreign financed capital has a significantly lower emission effect than domestic investment.

The analysis considers the effect of fixed capital on pollution emission as working through three channels: scale or economic growth, sectoral composition, and the pollution intensity of the industrial sector. While this decomposition, following the seminal works of Copeland and Taylor (2004, etc.), is meaningful from an analytical perspective, its translation into policy recommendations requires us to consider the three channels under societal objectives. Since economic activity (represented by our scale-channel) is necessary for development because it generates income, reducing pollution by reducing scale is not a generally meaningful option. Likewise, the scope of pollution reduction through shifting the sectoral composition of an economy away from industry is very limited, because industrial goods are needed to generate utility for a society. From a policy perspective, the most important channel to control is pollution intensity reflecting the state of environmental technology. Focusing on pollution intensity, our study finds foreign investment to be more environmentally friendly than domestic investment for all our pollution indicators except waste gas. However, compared to total pollution, the percentage gap between foreign and domestic investment is lower. Additional foreign investment of 100 000 RMB reduces pollution intensity between 63 per cent (for solid waste) and 80 per cent (for dust) more than domestic investment of the same amount does. From an environmental perspective, our study suggests that Chinese development planners should encourage foreign investment into Chinese industry, or at least should not discriminate against it relative to domestic investment.

While our model explicitly accounts for different pollution channels and for the interdependent determination of capital formation, economic growth, structural

changes and technology, the specification still suffers from being overly restrictive. Relatively large estimates for autonomous rates of change suggest that the impact of model variables may not have been fully captured by the respective model parameters. One important improvement could be to model capital formation (domestic and foreign) using dynamic specifications. Furthermore, the Cobb-Douglas specification, which implies problematic restrictiveness in terms of the factor substitution and factor productivities, should in future research be replaced by more flexible specifications.

Finally, while our perspective of taking the industrial sector as a whole provides an overall idea of the environmental effects of FDI, policy recommendations should be elaborated by focusing on particular sub-sectors. The Chinese government has always paid particular attention to pollution-intensive industries. The “Foreign Investment Industrial Guidance Catalogue” published by the government is based on sectors such as medicine, food, and oil production. Still, pollution emission greatly differs from one industry to another, and the relationship between FDI and pollution emission for specific industries should be examined in future studies.

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## Appendix A

Table A 1: Model diagnostics

A1 (a) individual equations

	Equation	Obs	Parms	RMSE	"R-sq"	$\chi^2$	P
water	lngdpad	475	32	0.113	0.988	45559	0
	lncomp	475	33	0.134	0.510	1950	0
	lnindewater	475	34	0.240	0.911	5419	0
	lnsfdi	475	32	0.409	0.798	1894	0
	lnsdc	475	30	1.843	0.864	3410	0
gas	lngdpad	475	32	0.113	0.988	45558	0
	lncomp	475	33	0.131	0.533	1946	0
	lnindegas	475	34	0.176	0.810	4417	0
	lnsfdi	475	32	0.409	0.798	1894	0
	lnsdc	475	30	1.843	0.865	3412	0
so2	lngdpad	475	32	0.114	0.988	45562	0
	lncomp	475	33	0.131	0.534	1945	0
	lnindeso2	475	34	0.221	0.936	7562	0
	lnsfdi	475	32	0.409	0.797	1895	0
	lnsdc	475	30	1.840	0.865	3399	0
dust	lngdpad	475	32	0.116	0.988	45547	0
	lncomp	475	33	0.124	0.583	1951	0
	lnindedust	475	34	0.463	0.851	3584	0
	lnsfdi	475	32	0.411	0.797	1889	0
	lnsdc	475	30	1.838	0.865	3392	0
solid	lngdpad	424	32	0.111	0.988	41244	0
	lncomp	424	33	0.139	0.417	1565	0
	lnindesolid	424	34	0.757	0.874	3050	0
	lnsfdi	424	32	0.339	0.821	1939	0
	lnsdc	424	30	1.717	0.831	2925	0
cod	lngdpad	475	32	0.114	0.988	45554	0
	lncomp	475	33	0.134	0.510	1949	0
	lnindecod	475	34	0.409	0.867	3387	0
	lnsfdi	475	32	0.409	0.797	1894	0
	lnsdc	475	30	1.840	0.865	3397	0

A1 (b) correlation between observed and predicted (3SLS and OLS) values on total



emission

	3SLS	OLS	OLS2
water	0.90	0.60	0.96
gas	0.86	0.82	0.93
olsso2	0.87	0.59	0.96
dust	0.83	0.22	0.87
solid	0.74	0.26	0.77
cod	0.87	0.17	0.90

## Estimation results<sup>13</sup>

Table A2: Scale equation

	dependent variable: <i>Y</i>					
	Water N=475	Gas N=475	SO2 N=475	Dust N=475	Solid N=424	Cod N=475
$\alpha_f (C_f)$	-0.0632** (-3.22)	-0.0631** (-3.22)	-0.0659*** (-3.36)	-0.0696*** (-3.55)	-0.194*** (-8.58)	-0.0661*** (-3.37)
$\alpha_d (C_d)$	0.0487*** (17.18)	0.0488*** (17.15)	0.0496*** (17.46)	0.0514*** (18.25)	0.0598*** (19.28)	0.0499*** (17.53)
$\alpha_L (L)$	0.194*** (4.08)	0.183*** (3.80)	0.180*** (3.81)	0.132** (2.84)	0.0794 (1.37)	0.168*** (3.51)
$\alpha_E (E)$	-0.0401** (-2.59)	-0.0428** (-2.73)	-0.0354* (-2.31)	-0.0208 (-1.37)	-0.0288 (-1.68)	-0.0323* (-2.08)
year	0.0921*** (48.58)	0.0923*** (48.52)	0.0918*** (48.50)	0.0910*** (48.32)	0.0949*** (48.24)	0.0917*** (48.31)
$\alpha_0(cons)$	-178.3*** (-47.48)	-178.6*** (-47.42)	-177.6*** (-47.35)	-175.8*** (-47.08)	-183.0*** (-46.94)	-177.3*** (-47.16)
Hausman ( $C_f, C_d$ )	157.30 (0.0000)	Hausman ( $C_f$ )	42.24 (0.0000)	Hausman ( $C_d$ )	389.24 (0.0000)	

Notes applicable to tables A1 to A5:

Estimates from a system equivalent to (7), see sections 2 and 4.1 for details.

\*, \*\*, and \*\*\* indicate estimates for which the hypothesis that the respective parameter equals zero was rejected at the 10, 1, and 0.1 percent levels.

Hausman test results: the test statistic and p-value (Chi squared distribution).

<sup>13</sup> We dropped the provincial dummy variables in the tables; it is available from the authors on request.

Table A3: Composition equation

	dependent variable: <i>Comp</i>					
	Water N=475	Gas N=475	SO2 N=475	Dust N=475	Solid N=424	Cod N=475
$\beta_f (C_f)$	-0.191*** (-6.46)	-0.182*** (-6.13)	-0.189*** (-6.42)	-0.150*** (-5.11)	-0.321*** (-9.62)	-0.203*** (-6.89)
$\beta_d (C_d)$	0.0625*** (12.93)	0.0604*** (12.41)	0.0603*** (12.53)	0.0555*** (11.56)	0.0695*** (12.13)	0.0624*** (12.96)
$\beta_L (L)$	-0.0240 (-0.30)	0.00367 (0.05)	0.00594 (0.07)	-0.00499 (-0.06)	0.128 (1.17)	0.00950 (0.12)
$\beta_Y (Y/POP)$	0.868*** (3.85)	0.937*** (4.12)	0.869*** (3.87)	1.230*** (5.49)	0.493 (1.57)	0.750*** (3.34)
$\beta_{YSQ} ((Y/POP)^2)$	-0.0616*** (-5.46)	-0.0635*** (-5.59)	-0.0593*** (-5.28)	-0.0736*** (-6.56)	-0.0418* (-2.46)	-0.0551*** (-4.90)
year	0.00255 (0.33)	-0.00123 (-0.16)	-0.00103 (-0.13)	-0.0133 (-1.73)	0.00869 (1.10)	0.00360 (0.47)
$\beta_0 (cons)$	-9.204 (-0.64)	-2.311 (-0.16)	-2.438 (-0.17)	20.14 (1.42)	-20.94 (-1.43)	-11.05 (-0.78)
Hausman ( $C_f, C_d$ )	10.07 (0.0732)	Hausman ( $C_f$ )	0.00 (1.0000)	Hausman ( $C_d$ )	10.43 (0.0639)	
Hausman ( $GDP$ )	7.59 (0.0553)					

Table A4: Pollution intensity equation

	dependent variable: <i>PI</i>					
	Water N=475	Gas N=475	SO2 N=475	Dust N=475	Solid N=424	Cod N=475
$\gamma_f$ ( $C_f$ )	-0.000508 (-0.01)	0.0455 (0.97)	-0.0365 (-0.65)	-0.198 (-1.90)	0.369 (1.57)	-0.154 (-1.44)
$\gamma_d$ ( $C_d$ )	-0.0340** * (-4.07)	-0.0164* (-2.51)	-0.0517** * (-6.50)	-0.146*** (-9.94)	-0.185*** (-5.41)	-0.0804** * (-5.35)
$\gamma_e$ ( $T_{env}$ )	0.00852 (0.78)	0.00106 (0.12)	-0.00224 (-0.22)	-0.00150 (-0.08)	0.000064 4 (0.00)	-0.0562** (-2.85)
$\gamma_g$ ( $T_{gen}$ )	0.0436 (1.26)	0.0118 (0.42)	0.000739 (0.02)	-0.0406 (-0.71)	-0.0866 (-0.74)	0.0141 (0.22)
$\gamma_s$ ( $ER$ )	0.166* (2.30)	0.133* (2.31)	0.248*** (3.63)	0.640*** (5.28)	1.175*** (4.36)	0.319* (2.44)
$\gamma_p$ ( $Pdens$ )	0.484 (1.44)	-0.351 (-1.30)	0.454 (1.42)	0.909 (1.62)	6.709*** (4.49)	1.610** (2.63)
year	-0.126*** (-18.87)	-0.0301** * (-5.69)	-0.0692** * (-10.94)	-0.0497** * (-4.30)	-0.253*** (-9.85)	-0.122*** (-10.15)
$\gamma_0$ ( $cons$ )	257.1*** (19.56)	62.94*** (6.06)	135.3*** (10.90)	105.1*** (4.63)	492.9*** (9.84)	248.3*** (10.51)
Water-						
Hausman ( $C_f$ , $C_d$ )	68.79 (0.0000)	Hausman ( $C_f$ )	11.76 (0.0675)	Hausman ( $C_d$ )	42.23 (0.0000)	

gas					
Hausman	8.06	Hausman	4.28	Hausman	30.91
$(C_f, C_d)$	(0.2335)	$(C_f)$	(0.6391)	$(C_d)$	(0.0000)
SO2					
Hausman	9.94	Hausman	1.23	Hausman	39.28
$(C_f, C_d)$	(0.1272)	$(C_f)$	(0.9756)	$(C_d)$	(0.0000)
dust					
Hausman	9.54	Hausman	2.69	Hausman	41.82
$(C_f, C_d)$	(0.1456)	$(C_f)$	(0.8463)	$(C_d)$	(0.0000)
solid					
Hausman	6.84	Hausman	5.83	Hausman	31.07
$(C_f, C_d)$	(0.3363)	$(C_f)$	(0.4420)	$(C_d)$	(0.0000)
COD					
Hausman	55.08	Hausman	10.71	Hausman	7.26
$(C_f, C_d)$	(0.0000)	$(C_f)$	(0.0978)	$(C_d)$	(0.2020)

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Table A5: Foreign financed capital stock equation

	<b>dependent variable: <math>C_f</math></b>					
	Water N=475	Gas N=475	SO2 N=475	Dust N=475	Solid N=424	Cod N=475
$\delta_Y \left(\frac{Y}{POP}\right)$	1.115*** (4.42)	1.157*** (4.58)	1.174*** (4.65)	0.896*** (3.57)	0.605* (2.56)	1.140*** (4.51)
$\delta_w(w)$	-0.334 (-1.58)	-0.337 (-1.58)	-0.322 (-1.51)	-0.180 (-0.86)	-0.379 (-1.84)	-0.304 (-1.43)
$\delta_S(ER)$	-0.592*** (-4.86)	-0.588*** (-4.83)	-0.600*** (-4.93)	-0.623*** (-5.13)	-0.374** (-3.25)	-0.606*** (-4.97)
$\delta_I(IS)$	0.128 (1.41)	0.103 (1.13)	0.0863 (0.95)	0.105 (1.16)	-0.158 (-1.78)	0.0865 (0.95)
year	-0.00387 (-0.14)	-0.00659 (-0.24)	-0.00841 (-0.30)	0.00566 (0.21)	0.0557* (2.23)	-0.00636 (-0.23)
$\delta_0(\text{cons})$	1.529 (0.03)	6.644 (0.12)	9.996 (0.19)	-17.11 (-0.32)	-113.1* (-2.35)	6.024 (0.11)
Hausman	15.53					
(GDP)	(0.0037)					

Table A6: Domestically financed capital stock equation

	dependent variable: $C_d$					
	Water N=475	Gas N=475	SO2 N=475	Dust N=475	Solid N=424	Cod N=475
$\varphi_f (C_f)$	3.510*** (12.48)	3.509*** (12.48)	3.523*** (12.52)	3.534*** (12.56)	4.702*** (15.87)	3.522*** (12.52)
$\varphi_Y (Y / POP)$	15.74*** (22.75)	15.74*** (22.79)	15.55*** (22.49)	15.41*** (22.34)	14.41*** (23.12)	15.56*** (22.47)
year	-1.355*** (-17.42)	-1.355*** (-17.46)	-1.335*** (-17.18)	-1.320*** (-17.02)	-1.272*** (-17.81)	-1.336*** (-17.16)
$\varphi_0 (cons)$	2586.1*** (17.21)	2586.9*** (17.25)	2547.5*** (16.97)	2518.3*** (16.81)	2430.7*** (17.61)	2549.7*** (16.95)
Hausman (GDP)	37.63 (0.0000)	Hausman ( $C_f$ )	41.38 (0.0000)			

## Appendix B: Derivation of capital effects

We derive here the effects of foreign and domestically financed fixed capital on pollution emissions in terms of the parameters estimated. These expressions are used to compute the effects presented in table 2.

Given from (7) that  $\frac{\partial C_d}{\partial C_f} = \phi_f$ , the derivative of equation (4) for economic scale

$Y$  with respect to  $C_f$ ,

$$\frac{\partial Y}{\partial C_f} = \frac{\partial(\alpha_0 e^{\alpha_f C_f} e^{\alpha_d C_d} L^{\alpha_L} E^{\alpha_E})}{\partial C_f} = \alpha_0 L^{\alpha_L} E^{\alpha_E} \left[ \frac{\partial e^{\alpha_f C_f}}{\partial C_f} e^{\alpha_d C_d} + e^{\alpha_f C_f} \frac{\partial e^{\alpha_d C_d}}{\partial C_d} \frac{\partial C_d}{\partial C_f} \right] = Y(\alpha_f + \alpha_d \phi_f)$$

implies that the relative change of  $Y$  associated with a one unit change of foreign

financed capital is  $\frac{\partial Y/Y}{\partial C_f} = \frac{\partial Y/\partial C_f}{Y} = \alpha_f + \alpha_d \phi_f$ .

Analogously, the respective effects on industrial composition ( $Comp$ ) and pollution

intensity ( $PI$ ) are  $\frac{\partial Comp/Comp}{\partial C_f} = \beta_f + \beta_d \phi_f$  and  $\frac{\partial PI/PI}{\partial C_f} = \gamma_f + \gamma_d \phi_f$ .

The derivative of equation (3) for pollution  $P$  with respect to  $C_f$  is

$$\frac{\partial P}{\partial C_f} = \frac{\partial[Y(C_f, \cdot) * Comp(C_f, \cdot) * PI(C_f, \cdot)]}{\partial C_f} = \frac{\partial Y}{\partial C_f} Comp PI + Y \frac{\partial Comp}{\partial C_f} PI + Y Comp \frac{\partial PI}{\partial C_f}.$$

Hence, the effect (in relative terms) of a one unit change of foreign financed capital on pollution through all three channels,  $Y$ ,  $Comp$ , and  $PI$  is

$$\frac{\partial P/P}{\partial C_f} = \frac{\partial P/\partial C_f}{P} = \frac{\partial Y/Y}{\partial C_f} + \frac{\partial Comp/Comp}{\partial C_f} + \frac{\partial PI/PI}{\partial C_f} = \alpha_f + \alpha_d \phi_f + \beta_f + \beta_d \phi_f + \gamma_f + \gamma_d \phi_f.$$

The effect of domestic capital is derived analogously. The derivative of equation (4) for economic scale  $Y$  with respect to  $C_d$ ,

$$\frac{\partial Y}{\partial C_d} = \frac{\partial(\alpha_0 e^{\alpha_f C_f} e^{\alpha_d C_d} L^{\alpha_L} E^{\alpha_E})}{\partial C_d} = \alpha_0 e^{\alpha_f C_f} L^{\alpha_L} E^{\alpha_E} \frac{\partial e^{\alpha_d C_d}}{\partial C_d} = Y \alpha_d, \text{ and the respective}$$



effects on  $Comp$  and  $PI$  are analogously  $\frac{\partial Comp}{\partial C_d} = Comp \beta_d$  and  $\frac{\partial PI}{\partial C_d} = PI \gamma_d$ .

Hence, we obtain for the total effect (in relative terms) of a one unit change of domestically financed capital on pollution

$$\frac{\partial P/P}{\partial C_d} = \alpha_d + \beta_d + \gamma_d.$$