UNIVERSITY OF ALBERTA
FACULTY OF ARTS
Department of Economics

Working Paper No. 2015-04

Credit Constraints, Technology Upgrading, and the Environment

Dana C. Andersen
University of Alberta

April 2015

Credit Constraints, Technology Upgrading, and the Environment

Dana C. Andersen*

February 15, 2015

Abstract

Access to credit is indispensable to financing firm investment and therefore bears on technology decisions and in turn environmental performance. This paper develops a tractable general equilibrium model to analyze the effect of credit constraints on production-generated pollution emissions. The model demonstrates that reducing credit constraints increases the scale of production (scale effect) and increases the number of firms taking up production (market size effect), while it also reduces emissions per unit of output (technique effect) and increases the share of firms investing in the technology upgrade (composition effect). Because the former and latter effects are plausibly confounding in nature, the net effect of credit constraints on pollution emissions is an empirical question. This paper demonstrates that, using variation in the timing of credit market reforms, reducing credit constraints significantly improves air pollution (sulphur dioxide and lead concentrations) in both developing and developed countries. The results are robust using various approaches, including two-way fixed effects, lagged dependent variables, and difference-in-differences.

JEL Classifications: D24, D53, Q53, Q55
Keywords: Credit constraints, choice of technology, air pollution

---

*Department of Economics, University of Alberta, 9-23 HM Tory, Edmonton, Alberta, T6G 2W1, Canada (email: dca@ualberta.ca). I thank Pinar Gunes, Ramón López, and Roberton Williams.

1 Introduction

Access to credit figures prominently in the analysis of firm investment decisions, and in turn firm performance and economic growth.[1] Credit market imperfections, including imperfect information, among other incentive problems, however, preclude investment in fixed assets, thereby constraining technology choices. Technology choices include investment in pollution abatement technologies (e.g., catalytic reduction technologies and sulphur dioxide "scrubber" systems), and more generally investment in technologies reducing input requirements, including fuel and material requirements in production (e.g., combined cycle gas turbines in electric power generation and continuous casting technologies in steel manufacturing).[2] Because pollution emissions are inextricably linked to technology and abatement choices, credit constraints bear on environmental performance whenever they influence investment decisions. While significant attention has been given to the relationship between credit constraints and economic performance, no studies to date have systematically explored the effect of credit constraints on environmental performance.

The contribution of this paper is twofold. First, I develop a tractable general equilibrium model to analyze the effect of credit constraints on the environment. The model divides the impact on pollution into firm scale and technique effects and general equilibrium composition and market-size effects. Due to the confounding nature of the effects, the overall effect of credit constraints on the environment is an empirical question, though the model demonstrates that reducing credit constraints plausibly leads to a net reduction in pollution emissions. Second, this paper empirically demonstrates that credit market reforms, while reducing imperfect information and widening credit markets, significantly improve air pollution (sulphur dioxide and lead concentration) in both developing and developed countries.

To analyze the effect of credit constraints on aggregate pollution emissions, this paper develops a general equilibrium model with heterogeneous firms based on the Dixit and Stiglitz (1977) model of monopolistic competition.[3] Firm heterogeneity accounts for the dispersion

[1] The literature on credit constraints and firm investment is vast, see Hubbard (1998) for a survey article. Midrigan and Xu (2014) estimate that credit constraints (frictions) reduce total factor productivity by 40 percent, while Hennessy and Whited (2007) estimate that credit frictions represent 13 and 25 percent of financing costs for large and small firms, respectively. Rajan and Zingales (1998), Levine et al. (2000), and Beck et al. (2000) demonstrate that financial development positively impacts economic growth.

[2] In the case electricity power generation, combined cycles increase thermal efficiency by using the exhaust of gas turbines to power a steam power plant, thereby reducing fossil fuel inputs. Similarly, in the case of steel manufacturing, continuous casting technologies have eliminated the most energy-intensive stages of production.

[3] The Dixit and Stiglitz (1977) model has been widely adopted in various economic fields, such as international trade (e.g., Melitz (2003)), as well the trade-and-the-environment literature (Copeland (2011) surveys the literature, including a section on models with monopolistic competition). One limitation of the Dixit and Stiglitz (1977) (constant elasticity) model is that firms' markups are exogenously fixed by the elasticity

of productivities and emissions intensities across firms and partitions the pool of potential firms, determining which firms will take up production and which firms will invest in a technology upgrade. In particular, initially identical firms face a dynamic forward looking entry decision, where paying a sunk market entry cost confers a random draw from a distribution of productivities. Firms with productivity draws conferring present value profits in excess of a fixed production cost will take up production, while firms with lower productivity draws will immediately exit.[4] Moreover, there exists a discrete technology upgrade, which extends the productivity draw by a fixed constant, and shifts the intensity of emissions in production. The model demonstrates that credit constraints, however, preclude investment in the technology upgrade for a subset of firms that would otherwise find the investment profitable.

Reducing credit constraints widens the subset of firms investing in the technology upgrade, increasing productivity and in turn output among impacted firms. While increasing output increases pollution emissions through the "scale effect," increased productivity reduces emissions intensity whenever productivity and emissions intensity are inversely related as evidenced by several empirical studies (Cole et al., 2005, 2008). This "technique effect" is reinforced whenever the technology upgrade is inherently cleaner or increases abatement efficiency. Therefore, among impacted firms, reducing credit constraints reduces pollution emissions if the technique effect outweighs the scale effect, which is more likely when (i) emissions intensity is declining in productivity, (ii) the upgrade is inherently cleaner, and (iii) the firm faces an inelastic demand curve.[5]

Taking into account general equilibrium effects implies that reducing credit constraints increases ex ante expected profits, thereby encouraging entry and resulting in a greater mass of firms taking up production. Consequently, pollution emissions increase through the "market-size effect." However, reducing credit constraints increases the share of firms investing in the technology upgrade, resulting in a "composition effect." Therefore, the partial equilibrium technique effect is reinforced at the macroeconomic level by the composition effect. Reducing credit constraints reduces aggregate emissions if the reduction in emissions among the additional firms investing in the technology upgrade outweighs the increase in emissions among the additional firms entering the market.

To resolve the ambiguity pointed out in the theoretical model, this paper assesses the effect of credit market reforms on pollution emissions. Specifically, I exploit variation in the

of substitution across varieties; however, this assumption turns out to be very convenient and ensures that the model remains tractable while retaining generality in respects that are of first order importance.

[4] I assume that there are an infinite number of time periods, and that every period there is an exogenous negative shock forcing a fraction of firms to exit. The analysis focuses on steady-state equilibria.

[5] Inelastic demand implies that an increase in productivity results in reduced prices rather than increased output, thereby limiting the scale effect.

timing of the establishment of a credit bureau registry, which facilitates the exchange of information across lenders and reduces imperfection information, across countries as exogenous variation in credit constraints. Using panel regression analysis, I find that the establishment of a credit bureau significantly reduces sulphur dioxide and lead concentrations, which are the primary production-generate pollution emissions, across 305 pollution monitoring sites in 37 countries. The results consistently indicate the credit reforms reduce pollution emissions using a number of approaches, including two-way fixed effects, lagged dependent variables, and sample restrictions. Using the preferred specification, credit reforms reduce sulphur dioxide and lead concentrations by approximately 0.5 and 1.1 percent after 5 years. Moreover, consistent with empirical studies documenting that the credit reforms are particularly important for credit intermediation in countries with French legal origin (Djankov et al., 2007), the empirical analysis demonstrates that the effect of credit reforms on pollution is particularly acute in French legal origin countries. Finally, following the approach suggested by Bertrand et al. (2004), the results are consistent using difference-in-differences, wherein pollution emissions are analyzed around the establishment of a credit bureau.

This paper is related to the empirical literature exploring the relationship between firm environmental performance and broadly-defined financial performance. Gray and Deily (1996) and Shadbegian and Gray (2005) find that more profitable firms are not more likely to comply with environmental standards, whereas Maynard and Shortle (2001) find that more profitable and less leveraged firms are more likely to invest in a clean technology.[6] Earnhart and Lizal (2006, 2010) report that profits are positively associated with air pollution emissions, whereas value added is negatively associated with air pollution emissions. Earnhart and Segerson (2012) contribute to the literature by pointing out that the correlation, if one exists, between financial performance and environmental performance might be the consequence of correlation between profits and unobservable factors, such as liquidity and solvency risk. Earnhart and Segerson (2012) is the first study to advance a conceptual framework to analyze various dimensions of financial status on compliance with environmental policy, and to conduct an empirical analysis of various dimensions of financial status, finding that liquidity and solvency risks do not, in general, play an important role in industrial wastewater discharges of chemical manufacturing facilities.

This paper is also related to the environmental Kuznets curve (EKC) literature, which posits that environmental damage follows an inverted U-shaped path over the path of economic development.[7] Because credit constraints significantly reduce total factor productivity

[6] Gray and Deily (1996) analyze 41 steel plants, Shadbegian and Gray (2005) analyze 116 pulp and paper mills, and Maynard and Shortle (2001) analyze 75 bleached kraft pulp mills.

[7] See Copeland and Taylor (2004) and Stern (2004) for surveys of the literature.

(TFP) Midrigan and Xu (2014) , and differences in GDP per capita are mostly accounted for by differences in TFP (Hall and Jones, 1999), reducing credit constraints represents an important source of economic growth. More importantly, because the source of growth matters in determining its environmental impact, growth achieved through credit intermediation and average TFP growth might entail less (or zero) environmental damage, while growth achieved through capital accumulation might increase pollution emissions. Thus, the development of financial institutions reducing credit constraints might partly explain the fall in the environmental damage, if one exists, over the development path.

While focusing on foreign investment rather than access to credit, a limited number of recent studies analyze the empirical relationship between financial development and environmental performance (Tamazian et al., 2009; Tamazian and Rao, 2010). These studies posit that financial liberalization attracts foreign direct investment, which in turn might increase domestic income and be associated with the introduction of cleaner technologies. While numerous proxies for financial development are used, these studies document that financial market liberalization and foreign direct investment are associated with CO_2 emissions in BRIC and transition countries.

The remainder of this paper is organized as follows. Section 2 presents the theoretical model. Section 3 discusses the data, estimation strategy, results, and robustness checks. Section 4 concludes.

2 Model

This section presents a general equilibrium model with heterogeneous firms facing monopolistic competition. Production requires paying a fixed production and distribution cost, and a variable factor of production (henceforth "labor"). Preferences are described over final goods using a constant elasticity of substitution utility function with elasticity of substitution $\sigma > 1$. Pollution emissions are generated as a byproduct of production and do not directly impact utility.

2.1 Consumers

Utility of a representative consumer exhibits constant elasticity of substitution (CES) with elasticity of substitution $\sigma > 1$

$$U = \left[\int_{v \in V} q(v)^{\frac{\sigma-1}{\sigma}} dv \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $q(v)$ is demand for variety v, and V is the set of available varieties.[8] Expenditure of the representative consumer is denoted Y and the price of variety v is denoted $p(v)$. Utility maximization, subject to the budget constraint $\int_{v \in V} p(v)q(v)dv = Y$, yields the isoelastic demand function for variety v

$$q(v) = YP^{\sigma-1}p(v)^{-\sigma} \tag{2}$$

where P is the CES price index.

2.2 Producers

There is a continuum of firms, each producing a unique variety. Production is linear in homogeneous labor, where the labor market is perfectly competitive, with an equilibrium wage rate w. Profit maximization for firms treating wages as given implies that marginal production costs are w/ϕ, where ϕ is the firm's productivity parameter. Access to credit, as explicated below, determines if the firm adopts a more productive technology, which increases productivity by a fixed scalar δ. In this case, marginal production costs are $w/[\phi(1+\delta)]$.

For notation, firms not adopting the more productive technology are denoted with the superscript c, while firms adopting the technology are denoted with the superscript $c+u$. Profit maximization implies that firms set prices equal to a constant markup over marginal cost

$$p^c(v) = \frac{w/\phi}{\rho} \quad \text{and} \quad p^{c+u}(v) = \frac{w/[\phi(1+\delta)]}{\rho} \tag{3}$$

where $\rho \equiv (\sigma - 1)/\sigma$. Using the derived isoleastic demand function implies that equilibrium output and revenue are given by

$$q^c(\phi) = YP^{\sigma-1}\left(\frac{w}{\phi\rho}\right)^{-\sigma} \quad \text{and} \quad r^c(\phi) = YP^{\sigma-1}\left(\frac{w}{\phi\rho}\right)^{1-\sigma} \tag{4}$$

$$q^{c+u}(\phi) = YP^{\sigma-1}\left(\frac{w}{\phi(1+\delta)\rho}\right)^{-\sigma} \quad \text{and} \quad r^{c+u}(\phi) = YP^{\sigma-1}\left(\frac{w}{\phi(1+\delta)\rho}\right)^{1-\sigma} \tag{5}$$

As expected, firms adopting the technology upgrade set lower prices, produce more, and

[8] Because the model abstracts from endogenous pollution policy responses, I do not consider disutility associated with environmental damage. However, incorporating environmental damage using a weakly-separable utility function (e.g., $W(Z, U)$ where U is given by equation and Z is aggregate pollution) would not change the analysis as the MRS (and thus the elasticity of substitution) of two varieties would be independent of pollution.

generate more revenue. That is,

$$\frac{q^{c+u}}{q^c} = (1+\delta)^\sigma > 1 \text{ and } \frac{r^{c+u}}{r^c} = (1+\delta)^{\sigma-1} > 1 \tag{6}$$

Pollution is emitted as a joint output of production, and is equal to emissions intensity (emissions per unit of output) times output. I assume that emissions intensities are given by

$$e^c(\phi) = \frac{1}{\phi^\alpha} \text{ and } e^{c+u}(\phi) = \frac{\gamma}{(\phi(1+\delta))^\alpha} \tag{7}$$

Emissions intensity therefore changes monotonically with firm productivity, with the technology parameter α determining the extent to which this is the case. The parameter γ reflects differences in emissions intensities not due to differences in productivity. The implications of various parameter values on pollution emissions are discussed below.

For simplicity and clarity, it is expedient to distinguish between output and emissions associated with the endowed technology and "additional" output and emissions associated with the technology upgrade, which I denote using the superscript u. For example, additional output is given by $q^u = q^{c+u} - q^c$. I will refer to variables corresponding to the endowed technology production as "constrained" values, while variables corresponding to the technology adoption as "unconstrained" values. Constrained variables therefore serve as the counterfactual values in the case that the firm adopts the technology upgrade, whereas the unconstrained variables serve as counterfactual "additional" values in the case that the firm does not adopt the technology upgrade.

It follows that additional output and revenue are given by

$$q^u = ((1+\delta)^\sigma - 1)\, q^c \text{ and } r^u = \Delta r^c \tag{8}$$

where $\Delta \equiv ((1+\delta)^{\sigma-1} - 1) > 0$. As expected, additional output and revenue are proportional to output and revenue generated by the endowed technology. Similarly, pollution emissions are given by

$$z^c(\phi) = \frac{q^c(\phi)}{\phi^\alpha} \text{ and } z^u(\phi) = (\Gamma - 1) z^c(\phi) \tag{9}$$

where

$$\Gamma = \frac{\gamma}{(1+\delta)^{\alpha-\sigma}} > 0 \tag{10}$$

Lemma 1: *Unconstrained pollution emissions z^u is negative if and only if $\Gamma < 1$. Thus, among firms investing in the technology upgrade, pollution emissions are less than* *counterfactual emissions if and only if*

$$\gamma < (1+\delta)^{\alpha-\sigma} \tag{11}$$

In this instance, I will refer to the technology upgrade as "pollution-decreasing," otherwise I will refer to the technology upgrade as "pollution-increasing."

Lemma 1 demonstrates that whether a technology upgrade is pollution-decreasing or pollution-increasing cannot be determined by *a priori* assumptions and is therefore an empirical question. However, the Lemma demonstrates that the technology upgrade is more likely pollution-decreasing whenever (i) the upgrade is inherently cleaner, (ii) the productivity gain is modest, (iii) emissions intensity is declining in productivity and (iv) the firm faces a more inelastic demand curve. While deriving sharp predictions is not possible, it is possible to shed some light on the relevant parameter regions.

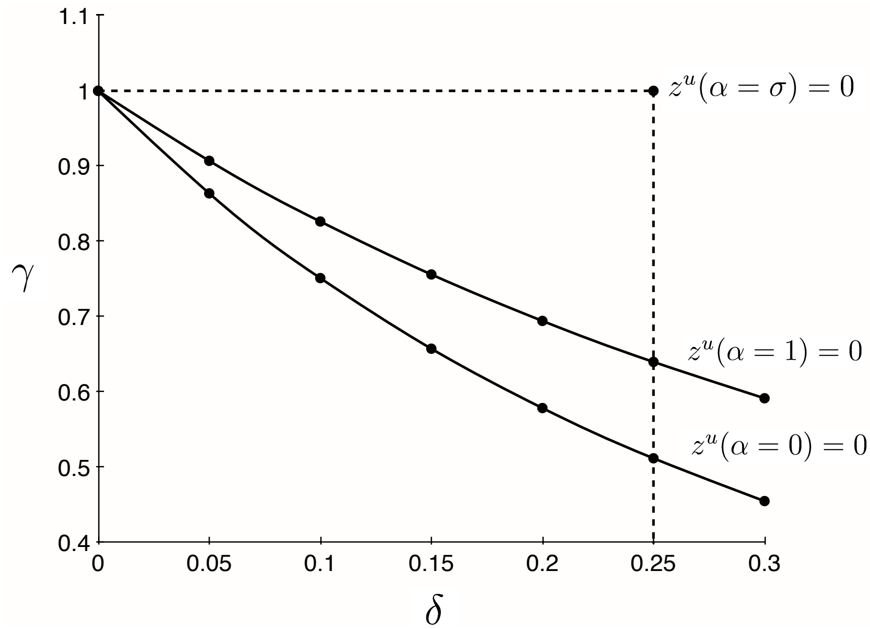
First, empirical studies document a strong correlation between productivity and environmental efficiency (Cole et al., 2005, 2008). This implies that (i) emissions intensity is decreasing in productivity ($\alpha > 0$) or that more productivity technology upgrades are inherently cleaner ($\gamma < 1$), or both.[9]

Second, empirical studies documenting the dispersion of firm productivities and studies assessing the extent that credit constraints influence productivity shed light on the extend that the technology upgrade increases productivity. Empirical studies document significant across-plant differences in measured productivity levels, even within narrowly defined industries, reflecting differences in technologies, at least in part. For example, Syverson (2004) estimates that average interquartile total factor productivity (TFP) ratios are between 1.34-to-1 and 1.56-to-1, depending on the measure. Moreover, Midrigan and Xu (2014) find that credit frictions reduce total factor productivity by up to 40 percent. Thus, while it appears that the technology upgrade corresponds to a nontrivial increase in productivity, empirical studies suggest that an upper bound is approximately 0.25.

Figure 1 plots $(\delta - \gamma)$ pairs such that the technology upgrade is pollution-increasing and pollution-decreasing using an elasticity of substitution $\sigma = 3$. The graph highlights that even after restricting the parameter space to plausible values ($\alpha \geq 0$, $\gamma \leq 1$, $\delta \leq 0.25$), both pollution-increasing and pollution-decreasing upgrades are relevant.

[9] Emissions intensity might be decreasing in productivity if more productive firms also have more productivity pollution "abatement" technologies. While the model does not explicitly account for pollution abatement, that consideration would be reflected in reduced form relationship between emissions intensity and productivity.

Figure 1: Pollution-decreasing and pollution-increasing upgrades



Notes: The graph uses an elasticity of substitution $\sigma = 3$. The area below the curves corresponds to a pollution-decreasing upgrade for $\alpha = 0$, while the area above the curves corresponds to a pollution-increasing upgrade for $\alpha = 1$. If $\alpha = 1$ ($\alpha = 0$) then the area between the curves corresponds to the pollution-decreasing (increasing) region as well.

2.2.1 Fixed and Upgrading Costs

All firms have a fixed production and distribution cost wf, whereas firms adopting the technology upgrade incur an additional fixed investment cost $w\beta$. Constrained and unconstrained profits, defined as corresponding revenue less labor and fixed costs, are given by

$$\pi^c = \frac{r^c}{\sigma} - wf \quad \text{and} \quad \pi^u = \frac{r^u}{\sigma} - w\beta \tag{12}$$

Credit constraints imply that upgrading costs cannot exceed a fraction of unconstrained revenue less labor cost.[10] That is, $w\beta \leq \theta r^u/\sigma$, where $0 < \theta < 1$. The assumption that $\theta < 1$ implies the existence of firms that find upgrading profitable but that do not generate sufficient revenue. Note that whether the constraint is applied to a fraction of unconstrained revenue or constrained revenue less corresponding labor cost is immaterial as the the former

[10]For simplicity, rather than explicitly modelling credit markets, the model uses the reduced-form parameter θ to sort potential borrowers, wherein more productive firms can access credit and less productive firms face credit rationing. This accords with the fact that more productive firms having greater internal liquidity to finance investments, greater assets to pledge as collateral, and less solvency risks, thereby increasing the expected return to lenders for a given interest rate. Consistent with this result, empirical studies document that small firms are more likely to face financing constraints (Hennessy and Whited, 2007).

is a fixed fraction of the latter.[11]

2.2.2 Zero Profit and Borrowing Constraint Conditions

The fixed production and upgrading costs define zero-profit credit constraint conditions. In particular,

$$\frac{r^c(\phi^c)}{\sigma} = wf \quad \text{and} \quad \frac{r^u(\phi^u)}{\sigma} = \frac{\beta w}{\theta} \tag{13}$$

where ϕ^c is the cutoff productivity for producing in the market, while ϕ^u is the cutoff productivity for investing in the technology upgrade. I assume firms that invest in the technology upgrade also find it profitable to produce without the technology upgrade, which follows if and only if $f < \theta\beta\Delta$, which implies that $r^c(\phi^c) < r^c(\phi^u) \Leftrightarrow \phi^c < \phi^u$. In other words, all firms that are able to finance the investment in the upgrade find it profitable to produce, but not all firms that find it profitable to produce are able to finance the investment in the upgrade.

2.2.3 Firm Entry and Exit

There is an unbounded pool of potential entrants deciding on paying a fixed market entry cost wf^e, which allows them to draw a random productivity from the common distribution $G(\phi)$. After realizing their productivity, firms then decide whether to start producing and whether to invest in the technology upgrade. There is an infinite number of time periods, and every period an exogenous negative shock precludes production for a fraction of producing firms η.

I assume that firm productivities are Pareto distributed, with the lower bound normalized to one, $G(\phi) = 1 - \phi^{-k}$ and $g(\phi) = k\phi^{-(k+1)}$.[12] To ensure that average per-firm output is finite, I assume that $k > \sigma$. With the ex ante productivity distribution being Pareto, the ex post productivity distributions of active firms and firms investing in the technology upgrade are Pareto. That is,

$$\mu^c(\phi) = \frac{k}{\phi}\left(\frac{\phi^c}{\phi}\right)^k \quad \text{and} \quad \mu^u(\phi) = \frac{k}{\phi}\left(\frac{\phi^u}{\phi}\right)^k \tag{14}$$

Free entry implies that the ex ante present value of expected profits has to be equal to the cost of entering the productivity draw.

$$(\phi^c)^{-k}\,\frac{\bar{\pi}}{\eta} = wf^e \tag{15}$$

[11] That is, $r^u = \Delta r^c$, implying that we can rescale $\theta^* = \theta/\Delta$, implying that $w\beta \leq \theta^* r^c/\sigma$.

[12] Eaton et al. (2011), among others, document that firm size approximately follows this distribution.

where $\bar{\pi}$ is average profits of active firms, and $(\phi^c)^{-k}$ is the ex ante probability that the firm produces.

2.2.4 Labor Market Clearing

Denote the mass of firms of entering the productivity draw as M^e, and the mass of firms taking up production and the mass of firms investing in the technology upgrade as M^c and M^u ($M^c > M^u$), respectively. Full employment in production, as well as market entry, is written as

$$L = M^e f^e + M^c \left(f + \int_{\phi^c}^{\infty} \frac{q^c}{\phi} \mu^c(\phi) d\phi \right) + M^u \left(\beta + \int_{\phi^u}^{\infty} \frac{q^u}{\phi(1+\delta)} \mu^u(\phi) d\phi \right) \tag{16}$$

where L is the exogenous labor supply. In equilibrium, the mass of firms taking up production is equal to the mass of firms stopping production, implying that $(\phi^c)^{-k} M^e = \eta M^c$. Using the zero profit and borrowing constraint conditions described in equation (13), as well as equations (5) and (8), the ratio of firms investing in the technology upgrade to firms taking up production is given by

$$\frac{M^u}{M^c} = \left(\frac{\phi^c}{\phi^u} \right)^k = \left(\frac{\theta \Delta f}{\beta} \right)^{\frac{1}{\sigma-1}} \in (0,1) \tag{17}$$

Thus the ratio of firms investing in the technology upgrade to all firms is determined by exogenous parameters, including θ, which increases the percentage of firms investing in the technology upgrade. Using equations (13), (15), and (17) in the employment condition (16) solve for the equilibrium M^c and M^u.[13] That is,

$$M^c = \frac{L/\kappa_1 \sigma}{\left(f + \left(\frac{\phi^c}{\phi^u} \right)^k \left(\frac{\beta}{\theta} \right) \right)} \quad \text{and} \quad M^u = \left(\frac{\phi^c}{\phi^u} \right)^k M^c \tag{18}$$

where $\kappa_1 = k/(1+k-\sigma)$.

2.3 Baseline Analysis

This section presents three main results. Result 1 analyzes the impact of reducing credit constraints on the mass of firms taking up production (market size effect) and the percentage of firms investing in the technology upgrade (composition effect). Result 2 analyzes the impact of reducing credit constraints on average constrained and unconstrained output (scale

[13] The details of the derivation are in the Appendix.

effect) and pollution emissions (technique effects) Result 3 describes necessary and sufficient conditions such that reducing credit constraints reduces aggregate emissions.

Result 1: Composition and Market Size Effect. *Reducing credit constraints increases the percentage of firms investing in the technology upgrade and the mass of firms taking up production. That is,*

$$\frac{\partial\left(\frac{M^u}{M^c}\right)/\frac{M^u}{M^c}}{\partial\theta/\theta}=\frac{1}{\sigma-1}>0 \tag{19}$$

$$\frac{\partial M^c/M^c}{\partial\theta/\theta}=\frac{\beta/\theta\left(\frac{\phi^c}{\phi^u}\right)^k\left(\frac{k}{\sigma-1}-1\right)}{\left(f+\left(\frac{\phi^c}{\phi^u}\right)^k\left(\frac{\beta}{\theta}\right)\right)}>0 \tag{20}$$

Proof: Clear from equations (17) and (18). □

Because reducing credit constraints increases the percentage of firms investing in the technology upgrade and the mass of firms taking up production then a corollary of Result 1 is that the mass of firms that invest in the technology upgrade must increase as well. That is,

$$\frac{\partial M^u/M^u}{\partial\theta/\theta}=\frac{\partial M^c/M^c}{\partial\theta/\theta}+\frac{k}{\sigma-1}>0 \tag{21}$$

On the other hand, the effect of reducing credit constraints on the mass of firms taking up production but not investing in the technology upgrade (M^{c-u}) is ambiguous. That is,

$$\frac{\partial M^{c-u}/M^{c-u}}{\partial\theta/\theta}=\frac{\partial M^c/M^c}{\partial\theta/\theta}\left(1-\frac{k}{\sigma-1}\left(\frac{M^u}{M^c}\right)\right) \tag{22}$$

Corollary: Productivity Cutoffs *Reducing credit constraints reduces the cutoff productivities for investing in the technology upgrade and taking up production. That is,*

$$\frac{\partial\phi^c/\phi^c}{\partial\theta/\theta}=-\frac{1}{k}\frac{\partial M^c/M^c}{\partial\theta/\theta}<0 \tag{23}$$

$$\frac{\partial\phi^u/\phi^u}{\partial\theta/\theta}=\frac{\partial\phi^c/\phi^c}{\partial\theta/\theta}-\frac{1}{\sigma-1}<0 \tag{24}$$

The Corollary follows immediately from the fact that the mass of firms investing in the technology upgrade and taking up production increases if and only if the corresponding productivity threshold decreases.

Define average output and average emissions for firms taking up production as $\bar{q}^c$ and $\bar{z}^c$. That is,

$$\bar{q}^c = \int_{\phi^c}^{\infty} q^c \mu^c(\phi) d\phi \quad \text{and} \quad \bar{z}^c = \int_{\phi^c}^{\infty} z^c \mu^c(\phi) d\phi \tag{25}$$

Next define average additional output and average additional emissions for firms investing in the technology upgrade as $\bar{q}^u$ and $\bar{z}^u$. That is,

$$\bar{q}^u = \int_{\phi^u}^{\infty} q^u \mu^u(\phi) d\phi \quad \text{and} \quad \bar{z}^u = \int_{\phi^u}^{\infty} z^u \mu^u(\phi) d\phi \tag{26}$$

The zero profit and credit constraint conditions (13) solve for average output and emissions across firms taking up productionThat is,

$$\bar{q}^c = \phi^c \left(\frac{f(\sigma - 1)k}{k - \sigma} \right) \quad \text{and} \quad \bar{z}^c = (\phi^c)^{1-\alpha} \left(f(\sigma - 1)\kappa_2 \right) \tag{27}$$

where $\kappa_2 = k/(1 + \alpha + k - \sigma) > 0$. Similarly, the zero profit and credit constraint conditions (13) solve for average additional output and emissions across firms investing in the technology upgrade. That is,

$$\bar{q}^u = \phi^u \left(\frac{(1+\delta)^\sigma - 1}{\Delta} \right) \left(\frac{(\beta/\theta)(\sigma - 1)k}{k - \sigma} \right) \tag{28}$$

$$\bar{z}^u = (\phi^u)^{1-\alpha} (\Gamma - 1) \left(\frac{(\beta/\theta)(\sigma - 1)\kappa_2}{\Delta} \right) \tag{29}$$

Result 2: Scale and Technique Effects (Average Output and Emissions). *Reducing credit constraints reduces average output and pollution emissions among firms taking up production. Moreover, it reduces average additional output and pollution emissions among firms investing in the technology upgrade. That is,*

$$\frac{\partial \bar{q}^c / q^c}{\partial \theta / \theta} = \frac{\partial \phi^c / \phi^c}{\partial \theta / \theta} < 0 \quad \text{and} \quad \frac{\partial \bar{z}^c / z^c}{\partial \theta / \theta} = (1 - \alpha) \frac{\partial \phi^c / \phi^c}{\partial \theta / \theta} < 0 \tag{30}$$

$$\frac{\partial \bar{q}^u / q^u}{\partial \theta / \theta} = \frac{\partial \phi^u / \phi^u}{\partial \theta / \theta} - 1 < 0 \quad \text{and} \quad \frac{\partial \bar{z}^u / z^u}{\partial \theta / \theta} = (1 - \alpha) \frac{\partial \phi^u / \phi^u}{\partial \theta / \theta} - 1 < 0 \tag{31}$$

Proof: Clear from equations (27), (28), and (29).

Result 2 demonstrates that reducing credit constraints decreases average output to a greater extent than it decreases emissions. Thus, reducing credit constraints increases average emissions intensity, defined as average emissions per unit of output.

Result 2 is the consequence of general equilibrium effects bearing on the composition of firms. In particular, reducing credit constraints encourages (i) taking up production among firms that otherwise would have exited the market and (ii) investment in the technology upgrade among firms that otherwise would have been credit constrained. In general, these are less productive firms with lower output and in turn lower emissions, though higher emissions intensity. A corollary of Result 2 is therefore that reducing credit constraints increases emissions intensity.[14]

Aggregate pollution emissions is given by average pollution emissions weighted by the mass of firms. That is,

$$Z = \bar{z}^c M^c + \bar{z}^u M^u \tag{32}$$

Define the "share" of pollution emissions from firms taking up production and firms investing in the technology upgrade as $s^c = \bar{z}^c M^c / Z$ and $s^u = \bar{z}^u M^u / Z$, where $s^c + s^u = 1$. The possibility that $z^u < 0$ implies the possibility that $s^c > 1$ and $s^u < 0$. The impact of reducing credit constraints on aggregate emissions is therefore

$$\frac{\partial Z/Z}{\partial\theta/\theta} = s^c \left(\frac{\partial(\bar{z}^c M^c)/\bar{z}^c M^c}{\partial\theta/\theta} \right) + s^u \left(\frac{\partial(\bar{z}^u M^u)/\bar{z}^u M^u}{\partial\theta/\theta} \right) \tag{33}$$

Thus, $s^u < 0$ alludes to the possibility that reducing credit constraints might lower aggregate pollution emissions.

Result 3: Aggregate Pollution Emissions. *The effect of reducing credit constraints on aggregate pollution emissions depends on the magnitude of the market size effect and the magnitude and sign of unconstrained emissions. That is,*

$$\frac{\partial Z/Z}{\partial\theta/\theta} = \xi_1 \varepsilon^M + \xi_2 s^u \tag{34}$$

where $\xi_1 = (k + \alpha - 1)/k$, $\xi_2 = (k + \alpha - \sigma)/(\sigma - 1)$, *and* $\varepsilon^M = \left(\frac{\partial M^c / M^c}{\partial\theta/\theta} \right)$.

Proof:

Equations (23) and (30) imply that

$$\frac{\partial(z^c M^c)/z^c M^c}{\partial\theta/\theta} = \xi_1 \left(\frac{\partial M^c / M^c}{\partial\theta/\theta} \right) > 0 \tag{35}$$

Equations (21), (24), and (31) imply that

$$\frac{\partial(z^u M^u)/z^u M^u}{\partial\theta/\theta} = \frac{\partial(z^c M^c)/z^c M^c}{\partial\theta/\theta} + \xi_2 > 0 \tag{36}$$

Using that $s^c + s^u = 1$, and equations (35) and (36) in (33) implies the desired result. □

[14] That is, $\bar{e}^c = \bar{z}^c/\bar{q}^c$ and $\bar{e}^u = \bar{z}^u/\bar{q}^u$ implies that $\frac{\partial\bar{e}^c/e^c}{\partial\theta/\theta} = -\alpha\frac{\partial\phi^c/\phi^c}{\partial\theta/\theta} > 0$ and $\frac{\partial\bar{e}^u/e^u}{\partial\theta/\theta} = -\alpha\frac{\partial\phi^u/\phi^u}{\partial\theta/\theta} > 0$.

Corollary *Reducing credit constraints decreases aggregate pollution emissions if and only if the share of additional pollution emissions is negative ($s^z < 0$) and sufficiently large in magnitude relative to the market size effect.* That is,

$$\left|\frac{\varepsilon^M}{s^u}\right| < \frac{\xi_2}{\xi_1} \Leftrightarrow \frac{\partial Z/Z}{\partial \theta/\theta} < 0 \tag{37}$$

Because the statement is an if and only if statement, reducing credit constraints increases aggregate emissions whenever the complement statement is true.

2.3.1 Discussion: From Theory to Estimation

The model divides the effect of credit constraints on aggregate emissions into technique, scale, composition, and market size. Reducing credit constraints reduces aggregate emissions if and only if the reduction in pollution emissions resulting in firms investing in the technology upgrade outweighs the increase in the mass of firms taking up production from a reduction in credit constraints. Because the average reduction in pollution emissions among firms investing in the technology is proportional to $\Gamma - 1$, which can be positive or negative according to Lemma 1, the net effect of credit constraints on pollution emissions is ambiguous. Moreover, while it might be possible to estimate the effect of reducing credit constraints on firm entry, it is not possible to estimate the share of emissions generated by unconstrained firms (s^u) as well as other parameters, ruling out the possibility of estimating structural parameters. The model, however, yields a relatively simple reduced-form relationship between credit constraints and aggregate pollution emissions ($\xi_1\varepsilon^M + \xi_2 s^u$). The aim of the empirical analysis is determine the sign of this reduced-form parameter, revealing the net effect of credit constraints on aggregate pollution emissions.

3 Empirical Analysis

Economy-wide credit market imperfections result in a subset of credit constrained firms that cannot invest in potentially profitable technology upgrades. An ideal analysis of the relationship between credit constraints and aggregate pollution emissions would entail "random" assignment of credit market imperfections across countries. In this case, comparing variation in pollution emissions across countries receiving more or less credit market imperfections would identify the causal effect of credit constraints on pollution emissions. Of course this experiment is impossible in practice, even in the case that the factors causing credit market imperfections are known.

This paper exploits institutional reforms occurring at different points in time across countries. Specifically I use the introduction of a credit bureau registry, which collect credit information on borrows and share it with lenders. The establishment of a credit bureau therefore is associated with a pronounced reduction in asymmetric information, which is a primary cause of credit market imperfections. Moreover, empirical studies demonstrate that the introduction of a credit registry facilitates credit intermediation and this paper corroborates that the reform increases borrowing.[15]

Thie empirical analysis uses both panel regression analysis and difference-in-differences (DID) approaches to analyze the effect of credit constraints on pollution emissions. The dependent variable is pollution concentration at a pollution monitoring site each year, where there are multiple sites within a country. In the panel regression analysis, identification takes advantage of within-country variation in credit reforms, and I introduce site and year effects, as well as country characteristics, such as output, income, and capital stocks. The DID approach looks at changes in pollution concentration around the credit reforms. Following the recommendation by Bertrand, Duflo, and Mullainathan (2004), I restrict the sample to countries that undertook the reform during the period of study (and have sufficient observations before and after the reform), and run a cross-section regression using average pollution emissions before and after the reform.

3.1 Data Sources

This paper uses data on private credit and credit institutional reforms from Djankov et al. (2007). Air pollution data is from the World Health Organization (WHO) Automated Meteorological Information System (AMIS), provided by the US Environmental Protection Agency (EPA). Country covariates are from the World Bank's World Development Indiators (WDI), human capital measures is from Barro and Lee (2013), and physical capital is from Amadou (2011).

3.1.1 Pollution

Because the theoretical model is relevant for production-generated pollution, I focus on pollution emitted as a byproduct of goods production, rather than consumption-generated pollution. The Global Environment Monitoring Systems (GEMS) was established to monitor the concentrations of various pollutants using comparable measuring devices, thereby producing consistent measures of pollution across developing and developed countries. Among the air pollutants with consistent data (sulfur dioxide, lead, ozone, volatile organic com-

[15] Djankov et al. (2007) reviews the empirical literature documenting that credit bureaus facilitate lending.

pounds, and carbon monoxide), sulfur dioxide (SO_2) and lead are the main air pollutions generated as a byproduct of goods production.[16]

Sulphur dioxide is a naturally occurring gas occurring from sources such as volcanoes, sea spray, and decaying organic matter, while anthropogenic sources are responsible for between one-third and one-half of total concentration (Kraushaar and Ristinen, 1993). On the other hand, lead is a naturally occurring mineral found in ores in the earth's crust, while anthropogenic sources are responsible for practically all of the total concentration found in the air. According to the United States EPA, sulphur dioxide emissions are generated from burning fossil fuels, typically at power plants (73%) and other industrial facilities (20%).[17] The primary sources of lead are ore and metal processing, and lead concentrations are highest near lead smelters. Exposure to both types of pollution cause adverse health effects: SO_2 is linked with a number effects on the respiratory system, while lead is toxic to many organs and tissues, and is particularly toxic to children, and is linked to various learning and behaviour disorders.

While GEMS has been recording pollution concentrations starting in the early 1970s, WHO reports that data comparability may be limited as monitoring techniques and procedures were modified to ensure consistency. Following the recommendations of WHO, I use the most consistent monitoring data starting in 1987 and ending in 1999, at which point GEMS discontinued pollution monitoring. In general, GEMS sites monitor sulfur dioxide, lead, or both; and the data are comprised of summary statistics for the yearly distributions of concentrations at each site.

The sulfur dioxide dataset consists of 2252 observations from 305 sites located in 37 countries, while the lead dataset consists of 783 observations from 137 sites located in 31 countries. The sulfur dioxide sample therefore encompasses a larger set of countries and greater number of observations per country, with the exception of 6 countries that monitor lead but not SO_2. Table 4 lists the set of countries in the SO_2 and lead samples, including the country sample years.

3.1.2 Credit Constraints

Adverse selection in credit markets arises when lenders are unable to observe characteristics of borrowers, such as the riskiness or viability of investments (Stiglitz and Weiss, 1981; Jaffee and Russell, 1976; among many others). Imperfect information therefore results in credit

[16] López et al. (2011) calculate the share of pollution generated from (i) production, (ii) consumption, or (iii) both. The shares of SO_2 are (i) 80%, (ii) 2%, and (iii) 18%, whereas lead is (i) 56%, (ii) 0%, (iii) and 44%.

[17] All data and statistics can be found at the EPA's website under the six "criteria pollutants" homepage: http://epa.gov/airquality/urbanair/.

rationing or high borrowing rates (or both), precluding potentially profitable investments. Conversely, reducing imperfect information mitigates credit rationing as lenders will be more willing to extend credit whenever they know more about potential borrowers, including past credit history and current indebtedness.

Credit registries facilitate the exchange of information across lenders, either voluntarily or imposed by regulation, concerning characters of existing or potential borrowers. The theoretical literature advances three effects of credit bureaus (Jappelli and Pagano, 2002). First, credit bureaus reduce asymmetric information, improving the lender's knowledge of credit applicants and permitting a more accurate prediction of the probably of repayment. Second, credit bureaus level the playing field within the credit market, thereby reducing informational rents and promoting competitive lending rates. Finally, credit bureaus increase the cost of defaulting to borrowers by excluding defaulting borrowers from accessing credit markets in the future, thereby serving as a disciplinary device to encourage repayment.

Credit registries exist in many countries and numerous empirical studies have demonstrated that it is an important factor in credit availability (Pagano and Jappelli, 1993; Jappelli and Pagano, 2002; Djankov et al., 2007). Djankov et al. (2007) significantly expand the data on credit institutions, gathering data in 133 countries over 25 years (representing every economy with a population over 1.5 million, except countries in civil conflict or inactive members of the World Bank, such as Afghanistan, Cuba, Iraq, Myanmar, and Sudan). The presence of a credit bureau is a dichotomous variable, indicating if a private credit bureau operates in the country. According to Djankov et al. (2007), "A private bureau is defined as a private commercial firm or nonprofit organization that maintains a database on the standing of borrowers in the financial system, and its primary role is to facilitate exchange of information amongst banks and financial institutions." Credit bureaus are typically owned by or affiliated with large international firms (Experian, Equinox, and TransUnion own, or are affiliated, with half of the bureaus in the sample of 129 countries).

3.1.3 Additional Covariates

Additional covariates are included in the panel analysis to account for the primary time-varying determinants of pollution emissions. In particular, changes in pollution emissions are likely influenced by changes in (1) output, (2) capital stocks, and (3) regulations (or more generally pollution policy). Unless indicated otherwise, all variables are from the World Bank's WDI. To account for output, or the scale of production, I use GDP per square kilometre in constant 2005 US$. Human capital is accounted for using measures of education and health, including the average number of years of education of the working population (over the age of 15) by Barro and Lee (2013) and life expectancy at birth. Physical capital per unit of GDP is from Amadou (2011) and measured using the perpetual-inventory method and initial capital stock computed as in Harberger (1978).

Data on regulations are unavailable for developing countries and, when available, are difficult to compare across countries due to their multidimensional nature. While the theoretical model presented herein does not account for endogenous regulations, several studies have demonstrated that the supply of pollution permits is uniquely determined by income of the representative consumer (Antweiler et al., 2001; López et al., 2011), which generates a reduced-form relationship between income and pollution emissions. All else constant, greater disposable income should decrease the supply of pollution permits, or equally, increase the effective tax on pollution, implying that income and the stringency of environmental regulations should be positively related. This paper uses consumption per capita as a proxy for disposable income, as well as pollution density, which determines the number of individuals affected by a given level of pollution concentration.

3.2 Analysis of Credit Bureau Reforms

As discussed, several papers advance that credit registries facilitate borrowing. This section corroborates that the establishment of a credit bureau increases lending among the countries in the sample of analysis. Specifically, I analyze the effect of establishing a credit bureau on Private Credit, defined as the ratio of credit from financial institutions to the private sector to GDP, from the International Monetary Fund (International Financial Statistics). Table 4 lists the countries in the sample of analysis and the year in which a credit bureau was established. Note that as of 2007, 11 countries had not established a credit bureau, and there were no instances of countries terminating bureaus once established.

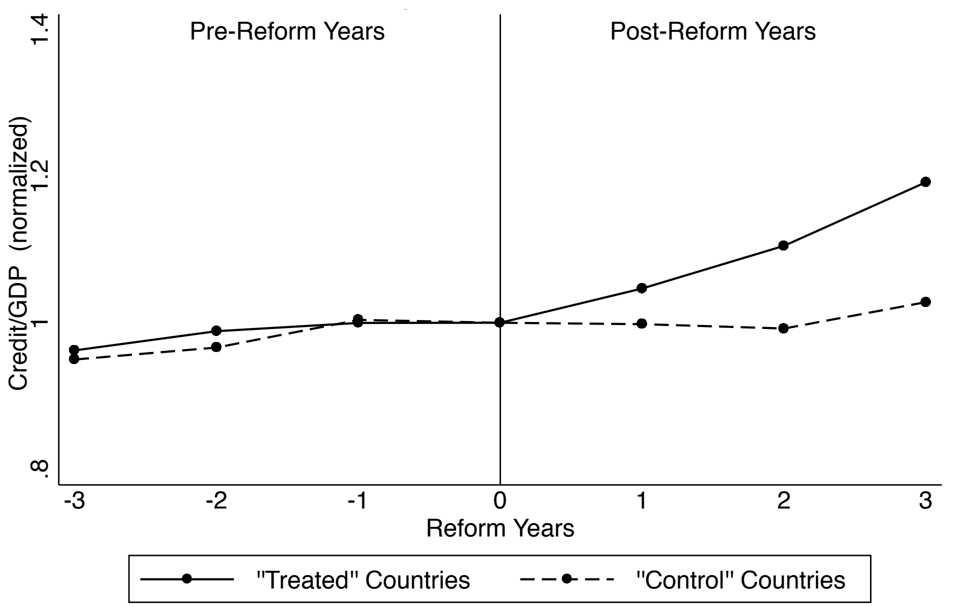
For transparency, I use a non-parametric approach to assess the impact of the establishment of a credit bureau on Private Credit. Figure 2 plots average "normalized" Private Credit for countries introducing credit bureaus ("Treated" countries) and countries not introducing credit bureaus ("Control" countries). The averages were calculated over all years in the sample of analysis as follows. Define Treated countries as the set of countries experiencing a credit reform during the sample of analysis. Consider a particular Treated country, denoting the year of the credit reform as year t^*, and the preceding three years as "Pre-Reform" years and the subsequent three years as "Post-Reform" years. All countries not experiencing a credit reform in Pre- and Post-Reform years are considered Control countries.[18] For each Treated and respective Control countries, Private Credit is normalized by dividing Private Credit in Pre and Post-Reform years by Private Credit in year t^*, with Private Credit in year

[18]Note that Control countries includes countries that (i) never introduced a credit bureau, (ii) always had a credit bureau, and (iii) experienced the reform in years outside the pre and post-reform years.

t^* is normalized to 1. Average Private Credit for Control countries in year t^* is then averaged over all Control countries. Finally, this routine is calculated for all Treated countries and corresponding control countries in respective years.[19]

Figure 2 demonstrates two noteworthy features. First, among both Treated and Control countries, Private Credit grew at roughly the same rate during the Pre-Reform period, typically not exceeding one percent annual growth. Second, Treated countries experienced rapid growth in Private Credit following the establishment of a credit bureau, increasing nearly 20 percent over the subsequent three years. Concurrently, Control countries experienced approximately the same rate of growth of Private Credit as in the Pre-Reform years. The observation that both Treated and Control countries experienced similar Private Credit growth in Pre-Reform years, but Private Credit grew more in Treated countries in the Post-Reform years, suggests that the credit reforms are driving Private Credit growth, rather than the other way around.

Figure 2: The Effect of Credit Reforms on Private Credit



Notes: Private Credit is the ratio of credit from financial institutions to the private sector to GDP. Averages are calculated for all countries experiencing credit reforms (Treated countries) and countries not experiencing credit reforms in corresponding years (Control countries). See text for more details.

While it is reassuring that credit reforms promote lending, it would also be reassuring to know that credit reforms are not correlated with factors that exert a direct influence on

[19] For example, suppose in the first Post-Reform year that normalized Private Credit is 1.1 for Treated countries and 1.05 for Control Countries. This implies that Private Credit grew by 10% on average in countries experiencing a credit reform, whereas in the same time period Private Credit grew by 5% on average in countries not experiencing a credit reform.

pollution emissions (after controlling for observable factors). One potential concern is that credit reforms are associated with rapid advancements in economic development or marked transformations in political institutions, which in turn bear on environmental policy and environmental performance. Towards this end, normalized GDP per capita and a composite index of democracy (Polity Score) are plotted using a similar approach as above.[20] Figure 4 in the Appendix demonstrates that trends in GDP per capita and Polity Scores are similar in both the Pre and Post-Reform periods.[21]

3.3 Panel Regression Analysis

The panel regression analysis assesses the effect of credit reforms on pollution emissions using the establishment of a credit bureau. For every country, let t^{est} represent the year in which a credit bureau was established, and $\mathbb{1}\{t \geq t^{est}\}$ represent an indicator variable if the country has a credit bureau at time t. The baseline regression model takes the form

$$\text{Pollution}_{sct} = \sum_{j=0}^{J} \psi_j \mathbb{1}\{t \geq t^{est}\} \times (t - t^{est})^j + \chi'_{ct}\Psi + u_t + u_s + \epsilon_{sct} \tag{38}$$

where s indexes sites, c indexes countries, and t indexes years. The dependent variable is log sulphur dioxide (SO_2) or log lead concentration.

Figure 2 demonstrates that credit reforms increase the rate of growth, rather than the level, of Private Credit. For $J = 0$, the coefficient ψ_0 represents the percentage change in pollution associated with the credit reform. The coefficient ψ_1 captures the additional effect of the credit reform in subsequent years, while ψ_2 captures diminishing effects (or second-order effects in general) of the credit reform in subsequent years, and so on.[22] Including the quadratic term (and higher polynomials) allows for the effect of the credit reforms far in the past to have little or no effect on pollution. The baseline analysis includes multiple values of $J = 0, 1$, and 2.

The year-specific effect (u_t) and site-specific effect (u_s) indicate that the model is a two-way-effects model that allows for the intercept to vary over sites and over time. Because

[20]Polity Score is a widely used measure of democracy, ranging from +10 (strongly democratic) to -10 (strongly autocratic) from the Centre for System Peace Policy IV project (http://systemicpeace.org/polity/polity4).

[21]Moreover, to the extent that potential unobservable factors that bear on pollution emissions are correlated with GDP per capita and Polity Scores, the observation that these factors are not correlated with credit reforms provides evidence that credit reforms are uncorrelated with these unobservable factors as well.

[22] Djankov et al. (2007) document that credit registries are particularly important when there are five or more years of historical data available. One plausible explanation is that creditworthiness is difficult to assess based on one or two years of credit history, thus the value of credit agencies increase over time as additional years of history are amassed.

the panel is short, I let the time-specific effects (u_t) be fixed effects (set of time dummies with one dummy dropped), and employ a mean difference model to eliminate the site-specific effect (u_s). The fixed effects regression therefore requires conditional orthogonally of random error component ϵ_{sct} and the explanatory variables. Because it is likely that the error term is correlated over time for a given site, I use cluster-robust standard errors that cluster on site.[23]

The vector χ'_{ct} includes country-level covariates, including GDP per square kilometre (GDP/AREA), household expenditures per capita (Consumption/Population), average number of years of education (Years Education), life expectancy at birth (Life Expectancy) and physical capital per GDP (Physical Capital/GDP).[24]

Table 3 reports summary statistics for the SO_2 and Lead sample of analysis. Note that "Control" corresponds to countries that always or never had a credit bureau during the sample of analysis (1987-1999), whereas "Treatment" corresponds to countries that experienced a credit reform sometime during the sample of analysis. The statistics are taken over sites, rather than countries, thereby weighting country-level variables by the frequency in which it appears in the sample.

3.3.1 Panel Regression Results

Table 1 reports the panel regression results, using log SO_2 (columns 1 to 3) and Lead (columns 4 to 6) as dependent variables. Columns 1 and 4 use a dummy for credit bureau established, columns 2 and 5 add (to the baseline model) the number of years elapsed since credit bureau established, and columns 3 and 6 add the number of years squared since the credit bureau established.[25]

Using SO_2 as a dependent variable, the credit reform dummy is statistically insignificant in all specifications. However, adding the number of years elapsed since the credit reform interacted with the credit reform dummy increases the goodness of fit, and suggests that credit reforms reduce pollution in subsequent years (column 2). Adding the number of years squared interacted with the credit reform dummy does not increase the goodness of fit, and the additional polynomial term is insignificant (column 3). Columns 2 and 3 suggest that credit reforms result in approximately a 0.25% reduction in SO_2 concentration after 5 years, a 0.5% reduction after 10 years, and a 1% reduction after 20 years (and so on).

[23]For example, it's possible that a large shock in pollution emissions might increase concentration over several years.

[24]All covariates are contemporaneous and in logs. The results are nearly identical using 1-year lags and quadratic covariates (available upon request). See Section 3.1.3 for a detailed discussion of the variables.

[25] That is, $J = 0, 1$, and 2 for columns (1 and 4), columns (2 and 5), and columns (3 and 6), respectively). Higher order polynomials insignificant and did not increase the goodness of fit.

Using lead as a dependent variable, the credit reform dummy is negative and statistically significant in all specifications. Adding the number of years elapsed since the credit reform interacted with the credit reform dummy increases the goodness of fit, and suggests that credit reforms reduce pollution in subsequent years (column 5). Adding the number of years squared interacted with the credit reform dummy increases the goodness of fit, and the additional polynomial term suggests that the negative effect is diminished in subsequent years (column 6). Column 6 suggests that credit reforms result in an immediate reduction in lead by approximately 0.6%, a 1.1% reduction after 5 years, a 1.6% reduction after 10 years, and a 2.6% reduction after 20 years (and so on).

While the theoretical model does not predict the sign of the covariates, the results are mostly consistent with expectations. For example, an increase in the scale of production increases pollution, with most models failing to reject a unitary elasticity. An increase in household disposable income, proxied by household consumption per capita, reduces SO_2 concentration, while in most specifications it does not significantly affect lead concentration. Finally, an increase in physical capital and human capital appears to decrease pollution, though the effects are insignificant in several specifications. One interpretation of this result is that lower levels of capital intensity might be associated with more depreciated or generally less efficient physical capital, which might generate more emissions. Similarly, lower levels of human capital might be associated with higher reliance on low skilled workers or less human-capital intensive industries.

3.3.2 Discussion of Panel Regression Results

What can explain the apparent differences between the SO_2 and Lead regressions? First, it appears that the model performs better using Lead as a dependent variable compared to SO_2, as evidenced by the nearly two-fold difference in adjusted R-squared. On the one hand, because anthropogenic sources represent only one-third to one-half of SO_2 concentration, it is unsurprising that the model explains "only" roughly 30 percent of the variation in concentration. On the other hand, anthropogenic sources represent nearly all of the lead concentration in the air, and consequently the model does a better job at explaining the data.

Second, it appears that the impact of credit bureau reforms is larger in magnitude for lead than SO_2. One possible explanation is that natural sources of variation might result in classical measurement error, thereby the point estimate would be biased downwards. However, the impacts are quite similar when considered as a percent of anthropogenic pollution. For example, after 10 years, a credit reform should reduce SO_2 concentration by 0.5%, while it should reduce lead concentration by 1.1%. However, if 50% of SO_2 concentration is from

Table 1: Determinants of SO_2 and Lead Concentration Using Site Fixed Effects

		SO_2			Lead	
	(1)	(2)	(3)	(4)	(5)	(6)
Bureau Established (BE)	–0.0078	0.0020	–0.0192	–0.7469†	–0.7303†	–0.5860†
$\mathbb{1}\{t \geq t^{est}\}$	(0.0687)	(0.0633)	(0.0665)	(0.1777)	(0.1826)	(0.1613)
#Years since BE		–0.0549†	–0.0468**		–0.0588**	–0.1047†
$\mathbb{1}\{t \geq t^{est}\}\times\ (t - t^{est})$		(0.0165)	(0.0221)		(0.0272)	(0.0262)
#Years since BE^2			–0.0001			0.0016†
$\mathbb{1}\{t \geq t^{est}\}\times\ (t - t^{est})^2$			(0.0002)			(0.0004)
GDP/Area	1.6067†	0.8414**	0.8168**	1.5887†	0.8528	1.2468**
	(0.3317)	(0.3436)	(0.3475)	(0.5054)	(0.5274)	(0.5027)
Consumption/Population	–1.8264†	–1.4659†	–1.4578†	0.7390	0.7978	1.6101**
	(0.3668)	(0.3572)	(0.3604)	(0.7091)	(0.6891)	(0.7208)
Physical Capital/GDP	–0.8262**	–1.0575†	–1.0852†	0.4047	0.1378	0.5976
	(0.3316)	(0.3252)	(0.3287)	(0.5194)	(0.4919)	(0.4894)
Years Education	–1.2671**	–1.0642	–0.7988	–0.3779	–0.2529	–3.7631†
	(0.6399)	(0.6651)	(0.7911)	(0.8187)	(0.8018)	(0.9865)
Life Expectancy	2.6826	–1.4360	–1.7244	4.1788	3.7751	9.4468
	(3.1622)	(3.0356)	(3.0781)	(8.0484)	(7.8452)	(7.4755)
Population Density	0.5497	0.7564	0.6316	–1.8886	–2.4524	–0.2097
	(1.0154)	(0.8986)	(0.9239)	(1.8361)	(1.7267)	(1.6751)
Adj. R-sq	0.311	0.329	0.329	0.602	0.607	0.624
Sites	298	298	298	137	137	137
Observations	2,157	2,157	2,157	783	783	783
Site Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Significance levels: *0.10, **0.05, and †0.01. The dependent variable and all covariates are expressed in logs. All estimations use cluster-robust standard errors that are clustered on sites.

anthropogenic sources, thencredit reform reduce the concentration attributed to human activity by 1%. Thus, the impacts on anthropogenic emissions are quite similar.

Third, what can explain the observation that credit reforms impact lead in both the short and long-run; however, credit reforms impact SO_2 only in the long-run? To the extent that technology adoption is irreversible, a marginal reduction in borrowing constraints will only have an impact on new firms entering the market and taking up production. Electricity generation, the primary source of SO_2 emissions, entails significant upfront capital investment, which is largely irreversible, and only a handful of firms enter the market every year. For example, upgrading to combined-cycle natural gas plant typically entails two years of construction and one additional year before achieving full capacity, while the plant life is roughly 30 years or more. Therefore, it is perhaps not surprising that credit reforms only have an impact on SO_2 emissions after several years.

3.4 Robustness Checks

Recall that identification in two-way fixed effects requires that, conditional on observables, countries experiencing credit reforms should have similar (counterfactual) trends in pollution as countries not experiencing credit reforms during the sample of analysis. However, countries experiencing credit reforms in years, and in some case decades, before the beginning of the sample and countries never experiencing credit reforms might be dissimilar in unobservable factors that vary over time and are correlated with pollution trends. Including only countries that experience credit reforms during the sample of analysis would mitigate this potential bias insofar as this restricted set of countries is less dissimilar in time varying factors that are correlated with pollution. Restricting the sample to only countries experiencing a credit reform during the sample of analysis reduces the number of sites in the SO_2 (lead) regressions from 298 (137) to 27 (16). An alternative approach in the same vein, but without reducing the sample size, is to account for time-specific effects unique to countries experiencing a credit reform during the sample.

Table 5 reports the panel regression results for restricting the sample to only countries experiencing a credit reform during the sample of analysis (columns 1 and 5) and including time-specific effects unique to the treatment group (columns 2 and 6). Because the restricted samples are very small, the results are sensitive to this restriction. In particular, using SO_2 as a dependent variable results in larger negative effect of credit reforms in the long run, while using lead as a dependent variable results in insignificant effects. On the other hand, including time-specific effects unique to the treatment group (columns 2 and 6) does not significantly change the results relative to the baseline panel regressions.

Besides consistency of the point estimates, another concern is obtaining correct standard errors to ensure accurate statistical inference. In particular, while estimation of the standard errors accounts for correlation of errors in different time periods for a given site, it does not account correlation of errors across sites. In particular, the estimated standard errors do not account for potential correlation of errors within countries. While not controlling for within-country error correlation may lead to misleadingly small standard errors, obtaining "cluster-robust" standard errors requires that the number of clusters essentially goes to infinity. The problem of too "few" clusters results in over-estimated standard errors and under-rejection of the null hypothesis. While there is no clear-cut definition of "few" most simulation studies find that less than 50 is "few" and even more with unbalanced clusters (Cameron and Miller, 2013). Because there are 37 (31) clusters in the SO_2 (lead) samples, and the clusters are highly unbalanced, clustering the standard errors on countries will result in overestimated standard errors.

Table 5 (columns 3 and 7) reports the panel regression results correcting for within-country error correlation. Even with few clusters, we can rule out zero effects of credit reforms for SO_2 and lead after 5 years.

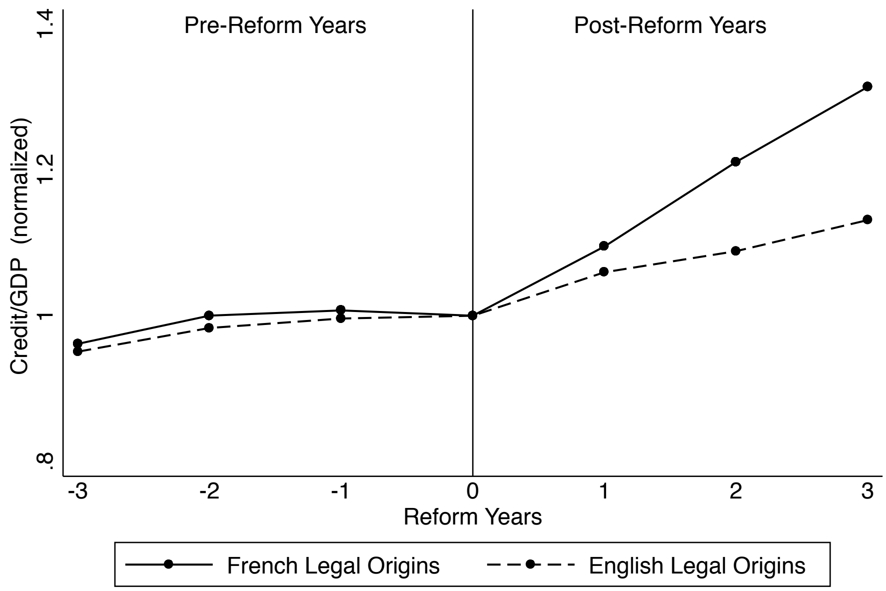
3.4.1 Differential Effect of Credit Reforms by Legal Origin

Legal origin has been demonstrated as an important determinant of investor protection and, in turn, the development of credit markets (La Porta et al., 1997, 1998, 2000; Beck et al., 2001). The English "common law system" is a legal system affording precedence to the adherence of previous "precendencial" decisions, which originated in England and spread throughout the colonies of the British Empire, including Australia, Canada, India, and the United States. The French "civil law system" is a legal system relying on codified statutes or regulations, which originated in France and was propagated to the countries conquered by Napoleon, including Spain and Portugal, and their colonies. Among English legal origin countries, credit market institutions (legal rules) provided strong protection to shareholders and creditors, while among civil law countries, especially French civil law countries, credit market institutions provided less protection to shareholders and creditors. As a result, common law countries have markedly higher "creditor rights" than civil law countries, and consequently have larger and wider credit markets.

Djankov et al. (2007) demonstrates that the establishment of a credit bureau is particularly beneficial to widening credit markets in French legal origin countries. One explanation is that the provision of information conferred from credit bureaus might serve as a substitute to creditor rights. In other words, creditors will be less concerned with recovering assets of defaulting borrowers whenever they are more informed about the creditworthiness of potential borrowers.

Figure 3 plots average normalized Private Credit for countries experiencing credit reforms in French and English legal origin countries, following the approach used in Section 3.2. However, in this case, Treated countries are divided into French and English legal legal origin countries. The effect of credit reforms on Private Credit is markedly greater in French legal origin countries compared to English legal origin countries. In particular, Private Credit growth in English and French legal origin countries is nearly identical in Pre-Reform years, but is approximately 20 percentage points higher in French legal origin countries in Post-Reform years.

Figure 3: The Effect of Credit Reforms: French vs. English Legal Origin



Notes: Private Credit is the ratio of credit from financial institutions to the private sector to GDP. Averages are calculated for all countries experiencing credit reforms in French legal origin and English legal origin countries.

Assessing the differential effect of credit reforms by legal origin is in the spirit of triple difference (or DDD) models. Here, the third difference is the difference in the impact of credit reforms between English legal origin and French legal origin countries. Towards this end, an indicator variable for French legal origin ("French") is interacted with (i) an indicator variable for credit bureau established and (ii) the number of years elapsed since the credit reform. The result are reported in Table 5 (columns 4 and 8).

The coefficient for French×Bureau Established represents the "additional" effect of the credit reform in French legal origin countries. The results suggest that among French legal origin countries the effect of credit reforms on pollution emissions is negative and statistically significant in both the short-run and the long-run for both SO_2 and Lead concentrations.[26] Moreover, there is a significant differential impact between French and English legal origin countries: in the long run, there is a larger (negative) effect on SO_2 concentration for French countries, while in both the short and long run, there is a larger effect on Lead concentration. For example, after 5 years, credit reforms reduce SO_2 concentration by 0.25% in English legal origin countries, whereas it reduces concentration by 0.42% in French legal origin countries. Similarly, credit reforms reduce lead concentration by 0.68% in English legal origin countries, whereas it reduces concentration by 2% in French legal origin countries.

3.5 Difference-in-Differences

Panel regressions are subject to criticism as they often omit relevant time-varying factors or because independent variables are endogenous. This section uses an alternative strategy, analyzing pollution concentration around credit reforms in a difference-in-difference (DD) framework. To ensure consistent standard errors, I follow the approach recommended by Bertrand et al. (2004). Specifically, I restrict the sample to countries experiencing a credit reform, and collapse the panel into a pre and post period. Restricting the sample implies that trends in pollution for countries experiencing credit reforms outside of a given timeframe serve as counterfactual trends for countries experiencing credit reforms within that timeframe.

Collapsing the data proceeds as follows. Suppose site s is in a country experiencing a credit reform in year t^*. Define pre and post reforms years as years $(t^* - N, ..., t^* - 1)$ and $(t^* + 1, ..., t^* + N)$, respectively. Moreover define the change in pollution for site s as average post-reform pollution less average pre-reform pollution as follows:

$$\Delta \text{Pollution}_s^T = \frac{1}{N} \sum_{t=t^*+1}^{t^*+N} \text{Pollution}_{st} - \frac{1}{N} \sum_{t=t^*-N}^{t^*-1} \text{Pollution}_{st} \tag{39}$$

However, during years $(t^* - N, ..., t + N)$ pollution might have changed systemically in non-reforming countries as well (countries experiencing a credit reform during the sample of analysis, but not during the pre or post-reform years). For year t^*, consider all countries not experienceing a credit reform anytime during the pre and post reform years. Denote average pollution for all non-reforming countries in year t as Pollution_t^C. Moreover, define the average change in pollution for all non-reforming countries as the average Pollution_t^C

[26] For French legal origin countries, the short-run effect on SO_2 is calculated by adding the first and third rows $(0.097 - 0.310 = -0.216)$, while the effect of additional years (long-run effect) is calculated by adding the second and fourth rows $(-0.070 + 0.030 = -0.04)$. And similar for Lead. The corresponding standard errors are calculated using the delta method.

over all post-reform years less the average Pollution_t^C over all pre-reform years:

$$\Delta \text{Pollution}^C = \frac{1}{N}\sum_{t=t^*+1}^{t^*+N} \text{Pollution}_t^C - \frac{1}{N}\sum_{t=t^*-N}^{t^*-1} \text{Pollution}_t^C \tag{40}$$

Average change in pollution in non-reforming countries $\Delta \text{Pollution}^C$ is used as a control variable for all countries experiencing a credit reform.

I run Ordinary least squares (OLS) using the change in pollution for site s as a dependent variable and the average change in pollution for all non-reforming countries as an independent variable as follows:

$$\Delta \text{Pollution}_s^T = \zeta_0 + \zeta_1 \Delta \text{Pollution}^C + \epsilon_s \tag{41}$$

The constant term ζ_0 therefore represents the average effect of the credit reform, controlling for systematic changes in non-reforming countries.

An inherent tradeoff exists in the selection of the optimal number of pre and post-reform years N. On the one hand, using few years increases the sample size and reduces the potential for omitted variable bias. On the other hand, it increases the probability of Type II error whenever the effect is delayed or incremental. Unfortunately the sample of sites experiencing credit reforms, especially for lead, is small, and consequently the range of years to explore is significantly constrained.

Table 2 reports the OLS results for SO_2 and Lead pollution concentration. The DD estimate of the impact of the credit reform for SO_2 is insignificant using one and two pre/post-reform years, while it is negative and significant using three pre/post reform years. This is consistent with the discussion in Section 3.3.2 and the long-run effect found in Section **??**. The DD estimate of the impact of the credit reform for Lead is negative and significant using one and two pre/post reform years. Moreover, the cumulative effect over two years is larger than the effect over the first year. Additional pre and post years results are insignificant and are not reported due to small sample size.

4 Conclusion

This paper presents a general equilibrium model to analyze the effect of credit constraints on the environment, demonstrating that the effect consists of technique, scale, composition, and market-size effects. Due to the confounding nature of the effects, the net effect of credit constraints on aggregate pollution emissions is ambiguous. The model derives relatively simple necessary and sufficient conditions for credit constraints to increase or decrease aggregate pollution emissions. Inspection of the relevant parameter space indicates that reducing credit

Table 2: Difference-in-Differences estimates of SO_2 and Lead Concentration

	SO_2			Lead	
Constant (DD estimate)	0.0640	–0.0356	-1.2045^{**}	$-1.1621^{\dagger}$	$-1.8871^{\dagger}$
	(0.0504)	(0.0665)	(0.4036)	(0.3767)	(0.3352)
Δ Pollution (Control Sites)	$0.6272^{\dagger}$	$0.6714^{\dagger}$	-2.3298^{*}	-2.2142^{*}	$-2.8062^{\dagger}$
	(0.1917)	(0.1703)	(1.2342)	(1.1108)	(0.6129)
# Pre and Post-Reform Years	1	2	3	1	2
Adj. R-sq	0.217	0.398	0.189	0.186	0.625
Observations	36	23	12	14	13

Notes: Significance levels: *0.10, **0.05, and †0.01.

constraints plausibility leads to a net reduction in pollution emissions.

Motivated by the ambiguity pointed out in the theoretical model, this paper exploits credit market reforms as exogenous variation in credit constraints. Using panel regression analysis, I find that the establishment of a credit bureau reduces sulphur dioxide and lead concentrations by 0.25% and 1.1% after 5 years, respectively. However, because anthropogenic sources represent between one-third and one-half of sulphur dioxide, the effect corresponds to between a 0.5% and 0.75% reduction in sulphur dioxide from anthropogenic sources. The results are consistent across various specifications, including lagged dependent variables and sample restrictions. The effect of credit reforms is significantly more pronounced in French legal origin countries, where credit reforms are more important for credit intermediation. For example, in French legal origin countries, credit reforms reduce sulphur dioxide concentration by 0.42% and lead concentration by 2% after 5 years. The results are also consistent using difference-in-differences, wherein pollution concentrations are analyzed around credit reforms.

This paper allays the concern that the tradeoff between economic development and environmental quality is inevitable. However, the source of economic development matters– growth achieved through credit intermediation and average productivity growth might reduce pollution, while growth achieved through capital accumulation might increase pollution. While many countries have established credit bureau registries, significant variation in other credit market institutions persists across countries, such as the legal rights of creditors against defaulting debtors, which have a significant positive role in credit intermediation (Djankov et al., 2007). Increasing creditor rights therefore represents a potential "win-win" policy reform in terms of promoting economic growth and reducing environmental damages.

This paper represents a first step toward understanding the role of credit constraints in environmental performance; however, it should not be the last. An important caveat is that the analysis presented here is relevant to production-generated pollution emissions (smokestack pollution), and might not apply to consumption-generated pollution (tailpipe). While it is plausible that reducing household credit constraints might reduce tailpipe pollution, extrapolating the results to tailpipe pollution should not be taken for granted. Towards this end, future research might develop a conceptual framework for assessing the effect of household credit constraints on tailpipe pollution and investigate the relationship using consumption-generated pollutants. Future research might also use firm or establishment level data to shed light on the relevant microeconomic parameters. Moreover, identification of the various paramters described in the model would provide greater insights into the role of credit constraints on pollution emissions.

References

Amadou, Diallo Ibrahima. 2011. STOCKCAPIT: Stata module to calculate physical capital stock by the perpetual-inventory method. *Statistical Software Components, Boston College Department of Economics.*

Antweiler, Werner, Brian R Copeland, and M Scott Taylor. 2001. Is free trade good for the environment? *The American Economic Review* 91: 877–908.

Barro, Robert J and Jong Wha Lee. 2013. A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics* 104: 184–198.

Beck, Thorsten, Asli Demirgüç-Kunt, and Ross Levine. 2001. Legal theories of financial development. *Oxford Review of Economic Policy* 17: 483–501.

Beck, Thorsten, Ross Levine, and Norman Loayza. 2000. Finance and the sources of growth. *Journal of Financial Economics* 58: 261–300.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. 2004. How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics* 119: 249–275.

Cameron, A Colin and Douglas L Miller. 2013. A practitioner's guide to cluster-robust inference. Unpublished Manuscript, Department of Economics, University of California, Davis.

Cole, Matthew A, Robert J R Elliott, and Kenichi Shimamoto. 2005. Industrial characteristics, environmental regulations and air pollution: an analysis of the UK manufacturing sector. *Journal of Environmental Economics and Management* 50: 121–143.

Cole, Matthew A, Robert J R Elliott, and Shanshan WU. 2008. Industrial activity and the environment in China: An industry-level analysis. *China Economic Review* 19: 393–408.

Copeland, Brian A. 2011. Trade and the environment, in Daneil Bernofen, Rod Falvey, David Greenaway, and Udo Kreickemeier: Palgrave Handbook of International Trade.

Copeland, Brian R and M Scott Taylor. 2004. Trade, growth, and the environment. *Journal of Economic Literature* 42: 7–71.

Dixit, Avinash K and Joseph E Stiglitz. 1977. Monopolistic competition and optimum product diversity. *American Economic Review* 67: 297–308.

Djankov, Simeon, Caralee McLiesh, and Andrei Shleifer. 2007. Private credit in 129 countries. *Journal of Financial Economics* 84: 299–329.

Earnhart, Dietrich and Lubomir Lizal. 2006. Effects of ownership and financial performance on corporate environmental performance. *Journal of Comparative Economics* 34: 111–129.

——— 2010. Effect of Corporate Economic Performance on Firm-Level Environmental Performance in a Transition Economy. *Environmental and Resource Economics* 46: 303–329.

Earnhart, Dietrich and Kathleen Segerson. 2012. The influence of financial status on the effectiveness of environmental enforcement. *Journal of Public Economics* 96: 670–684.

Eaton, Jonathan, Samuel Kortum, and Francis Kramarz. 2011. An anatomy of international trade: evidence From french firms. *Econometrica* 79: 1453–1498.

Gray, Wayne B and Mary E Deily. 1996. Compliance and enforcement: Air pollution regulation in the US steel industry. *Journal of Environmental Economics and Management* 31: 96–111.

Hall, Robert E and Charles I Jones. 1999. Why Do Some Countries Produce So Much MOre Output Per Worker Than Others?. *The Quarterly Journal of Economics* 114: 83–116.

Harberger, Arnold. 1978. Perspectives on Capital and Technology in Less Developed Countries. *M.J. Arts and A.R. Nobay (Eds): Conetemporary Economic Analysis, London*

Hennessy, Christopher A and Toni M Whited. 2007. How Costly Is External Financing? Evidence from a Structural Estimation. *The Journal of Finance* LXII:.

Hubbard, R Glenn. 1998. Capital-market imperfections and investment. *Journal of Economic Literature* 36: 193–225.

Jaffee, Dwight M and Thomas Russell. 1976. Imperfect information, uncertainty, and credit rationing. *The Quarterly Journal of Economics* 90: 651–666.

Jappelli, Tullio and Marco Pagano. 2002. Information sharing, lending and defaults: Cross-country evidence. *Journal of Banking & Finance* 2017–2045.

Kraushaar, Jack J and Robert A Ristinen. 1993. *Energy and Problems of a Technical Society*: Wiley-VCH, 2nd edition.

La Porta, Rafael, Florencio Lopez-de Silanes, Andrei Shleifer, and Robert W Vishny. 1997. Legal determinants of external finance. *The Journal of Finance* 52: 1131–1150.

——— 1998. Law and finance. *Journal of Political Economy* 106: 1113–1155.

——— 2000. Investor protection and corporate governance. *Journal of Financial Economics* 58: 3–27.

Levine, Ross, Norman Loayza, and Thorsten Beck. 2000. Financial intermediation and growth: Causality and causes. *Journal of Monetary Economics* 46: 31–77.

López, Ramón, Gregmar I Galinato, and Asif Islam. 2011. Fiscal spending and the environment: Theory and empirics. *Journal of Environmental Economics and Management* 62: 180–198.

Maynard, Leigh J and James S Shortle. 2001. Determinants of cleaner technology investments in the U.S. bleached kraft pulp industry. *Land Economics*.

Melitz, Marc. 2003. The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica* 71: 1695–1725.

Midrigan, Virgiliu and Daniel Yi Xu. 2014. Finance and misallocation: evidence from plant-level data. *American Economic Review* 104: 422–458.

Pagano, Marco and Tullio Jappelli. 1993. Information sharing in credit markets. *The Journal of Finance* 48: 1693–1718.

Rajan, Raghuram G and Luigi Zingales. 1998. Financial dependence and growth. *The American Economic Review* 88: 559–586.

Shadbegian, Ronald J and Wayne B Gray. 2005. Pollution abatement expenditures and plant-level productivity: A production function approach. *Ecological Economics* 54: 196–208.

Stern, David I. 2004. The rise and fall of the environmental kuznets Curve. *World Development* 32: 1419–1439.

Stiglitz, Joseph E and Andrew Weiss. 1981. Credit rationing in markets with imperfect information. *The American Economic Review* 71: 393–410.

Syverson, Chad. 2004. Product substitutability and productivity dispersion. *Review of Economics and Statistics* 86: 534–550.

Tamazian, Artur, Juan Piñeiro Chousa, and Krishna Chaitanya Vadlamannati. 2009. Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries. *Energy Policy* 246–253.

Tamazian, Artur and B Bhaskara Rao. 2010. Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Economics* 32: 137–145.

Mathematical Appendix

Derivation of Equation (18):

$$M^c = \frac{L/\kappa_1\sigma}{\left(f + \left(\frac{\phi^c}{\phi^u}\right)^k \left(\frac{\beta}{\theta}\right)\right)} \tag{42}$$

Average profits for producing firms in the economy is

$$\bar{\pi} = \bar{\pi}^c + \left(\frac{\phi^c}{\phi^u}\right)^k \bar{\pi}^u = \left(\frac{\bar{r}^c}{\sigma} - wf\right) + \left(\frac{\phi^c}{\phi^u}\right)^k \left(\frac{\bar{r}^u}{\sigma} - w\beta\right) \tag{43}$$

where $(\phi^c/\phi^u)^k$ is the share of firms investing in the technology upgrade. Average revenue is solved using the zero profit and borrowing-constraint conditions (13), as well as (8). That is,

$$\begin{aligned} \bar{r}^c &= \int_{\phi^c}^{\infty} r^c \mu^c(\phi) d\phi \\ &= \int_{\phi^c}^{\infty} Y P^{\sigma-1} \left(\frac{w}{\phi\rho}\right)^{1-\sigma} \left(\frac{k}{\phi}\right) \left(\frac{\phi^c}{\phi}\right)^k d\phi \\ &= r^c(\phi^c)\kappa_1 = wf\sigma\kappa_1 \end{aligned} \tag{44}$$

$$\begin{aligned} \bar{r}^u &= \int_{\phi^u}^{\infty} r^u \mu^u(\phi) d\phi \\ &= \Delta \int_{\phi^u}^{\infty} Y P^{\sigma-1} \left(\frac{w}{\phi\rho}\right)^{1-\sigma} \left(\frac{k}{\phi}\right) \left(\frac{\phi^u}{\phi}\right)^k d\phi \\ &= \Delta r^c(\phi^u)\kappa_1 = r^u(\phi^u)\kappa_1 = \frac{w\beta\sigma}{\theta}\kappa_1 \end{aligned} \tag{45}$$

Using equations (44) and (45) in (42) implies that

$$\bar{\pi} = wf(\kappa_1 - 1) + \left(\frac{\phi^c}{\phi^u}\right)^k \left(\frac{w\beta}{\theta}\right)(\kappa_1 - \theta) \tag{46}$$

Using that $(\phi^c)^{-k} M^e = \eta M^c$ and (16) implies that labor clearing condition is given by

$$\frac{L}{M^c} = \eta(\phi^c)^k f^e + \left(f + \int_{\phi^c}^{\infty} \frac{q^c}{\phi}\mu^c(\phi)d\phi\right) + \left(\frac{\phi^c}{\phi^u}\right)\left(\beta + \int_{\phi^u}^{\infty} \frac{q^u}{\phi(1+\delta)}\mu^u(\phi)d\phi\right) \tag{47}$$

Equations (13) and (8) solve for constrained and unconstrained labor demand:

$$\int_{\phi^c}^{\infty} \frac{q^c}{\phi}\mu^c(\phi)d\phi = \int_{\phi^c}^{\infty} YP^{\sigma-1}\left(\frac{w}{\phi\rho}\right)^{-\sigma}\left(\frac{k}{\phi}\right)\left(\frac{1}{\phi}\right)\left(\frac{\phi^c}{\phi}\right)^k d\phi$$
$$= r^c(\phi^c)\left(\frac{\phi^c\rho}{w}\right)\left(\frac{\kappa_1}{\phi^c}\right) \tag{48}$$
$$= f(\sigma-1)\kappa_1$$

$$\int_{\phi^u}^{\infty} \frac{q^u}{\phi(1+\delta)}\mu^u(\phi)d\phi = \Delta\int_{\phi^u}^{\infty} YP^{\sigma-1}\left(\frac{w}{\phi\rho}\right)^{-\sigma}\left(\frac{k}{\phi}\right)\left(\frac{1}{\phi}\right)\left(\frac{\phi^u}{\phi}\right)^k d\phi$$
$$= \Delta r^c(\phi^u)\left(\frac{\phi^c\rho}{w}\right)\left(\frac{\kappa_1}{\phi^c}\right)$$
$$= r^u(\phi^u)\left(\frac{\phi^c\rho}{w}\right)\left(\frac{\kappa_1}{\phi^c}\right) \tag{49}$$
$$= \frac{\beta(\sigma-1)\kappa_1}{\theta}$$

Equation (47) can therefore be expressed as

$$\frac{L}{M^c} = \eta(\phi^c)^k f^e + f\left(1+(\sigma-1)\kappa_1\right) + \left(\frac{\phi^c}{\phi^u}\right)\beta\left(1+\frac{(\sigma-1)\kappa_1}{\theta}\right) \tag{50}$$

Using the free entry condition (15) implies that we substitute for $\eta(\phi^c)^k f^e$ in (50). That is,

$$\eta(\phi^c)^k f^e = f\left(\kappa_1 - 1\right) + \left(\frac{\phi^c}{\phi^u}\right)^k\left(\frac{\beta}{\theta}\right)\left(\kappa_1-\theta\right) \tag{51}$$

Using (51) in (50) implies that

$$\frac{L}{M^c} = \sigma\kappa_1\left(f + \left(\frac{\phi^c}{\phi^u}\right)^k\left(\frac{\beta}{\theta}\right)\right) \tag{52}$$

As desired. □

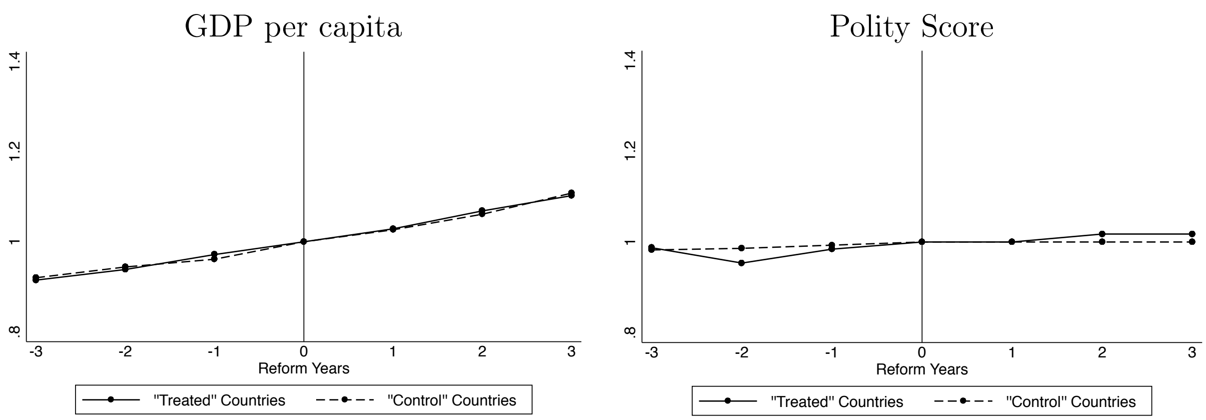
Tables Appendix

Table 3: Summary Statistics for SO_2 and Lead: Mean and Standard Deviation

	Sulfur Dioxide Sample				Lead Sample			
	Control Countries		Treated Countries		Control Countries		Treated Countries	
Pollution (SO_2 or Lead)	27.26	(35.86)	52.75	(40.55)	0.22	(0.28)	0.35	(0.52)
Established Private Credit	0.68	(0.47)	0.51	(0.50)	0.65	(0.48)	0.72	(0.45)
Years Established	21.38	(23.45)	2.08	(2.81)	19.62	(23.76)	3.02	(2.97)
Credit/GDP	74.54	(45.16)	38.16	(22.90)	80.37	(45.03)	36.87	(29.67)
GDP/Area ($\times$1 mil)	2.04	(2.94)	1.37	(1.72)	2.13	(3.15)	1.27	(2.02)
Physical Capital/GDP	3.56	(1.73)	3.59	(0.91)	3.73	(1.89)	3.44	(0.85)
Population Density	94.02	(89.86)	154.09	(154.02)	100.93	(96.03)	150.65	(169.45)
Consumption/Pop ($\times$1000)	9.92	(6.07)	7.66	(3.78)	9.72	(6.41)	7.11	(3.69)
Years Education	8.29	(2.32)	8.79	(1.48)	8.63	(2.34)	7.89	(2.18)
Life Expectancy	72.91	(5.62)	72.65	(3.96)	73.21	(5.23)	72.84	(3.70)

Notes: Standard deviations are in parenthesis. Control countries refers to sites in countries experiencing a credit reform during the sample of analysis, whereas Treated countries refers to sites in countries not experiencing a credit reform (always or never had a credit bureau). Statistics are calculated over sites. Pollution is measures in micrograms per cubic metre.

Figure 4: The Effect of Credit Reforms on Economic Development and Political Institutions



Notes: Averages are calculated for all countries experiencing credit reforms (Treated countries) and countries not experiencing credit reforms in corresponding years (Control countries). See text for more details.

Table 4: List of countries and reform years

			Sulfur Dioxide		Lead	
Country	Sample Years	Reform Year	#Sites	#Sites×Years	#Sites	#Sites×Years
Argentina	1994-1998	1957	3	9	3	8
Australia	1987-1999	1968	5	36	8	51
Austria	1989-1999	1964	3	33	3	36
Brazil	1987-1999	1968	15	94		
Canada	1987-1993	1989	7	41	6	37
Chile	1990-1995	1928	3	15		
China	1987-1998		26	320		
Colombia	1999-1999	1981	6	6		
Costa Rica	1996-1996	1992	5	5	5	15
Denmark	1990-1994	1971	1	5	1	5
Ecuador	1987-1998		7	41	3	3
El Salvador	1996-1999	1996			5	14
Finland	1987-1999	1961	4	30	3	25
France	1988-1999		22	147	6	11
Germany	1987-1998	1927	20	228	10	83
Guatemala	1994–1997	1998			6	24
Greece	1987-1998	1993	3	35		
Honduras	1994–1999				6	18
Hungary	1991-1999	1996	10	51		
India	1987-1997		30	249	10	68
Japan	1987-1995	1979	6	51	6	48
Korea Rep.	1987-1998	1995	10	99	5	40
Latvia	1994-1996		5	15	5	14
Lithuania	1996-1999		11	43	5	13
Mexico	1987-1999	1989	21	150	6	72
New Zealand	1987-1999	1982	3	26	3	37
Nicaragua	1998–1998				1	1
Panama	1996–1998				3	9
Peru	1997-1999	1995	1	3	1	3
Philippines	1987-1993	1998	4	20		
Portugal	1987-1995	1996	3	16	3	13
Romania	1991-1996		3	17	2	3
South Africa	1987-1999	1901	10	51	4	18
Spain	1987-1999	1957	6	55		
Sweden	1999-1999	1977	1	1		
Switzerland	1987-1999	1969	5	24	4	16
Thailand	1989-1993	1999	3	7	3	21
Turkey	1988–1999	1999	10	91	4	29
United Kingdom	1987-1999	1981	17	114	4	21
United States	1987-1999	1974	4	23		
Uruguay	1999–1999	1954	2	2		
Venezuela Rep.	1987-1998		10	99	3	27
Total			305	2252	137	783

Table 5: Robustness: Determinants of SO_2 and Lead Concentration Using Site Fixed Effects

	SO_2				Lead			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Bureau Established (BE)	0.0555	0.0853*	–0.0356	0.0974	1.0891	–0.8084†	–0.7303**	–0.3996**
$\mathbb{1}\{t \geq t^{est}\}$	(0.0746)	(0.0490)	(0.0787)	(0.0671)	(1.0792)	(0.2504)	(0.3448)	(0.1802)
#Years since BE	–0.2594†	–0.0529†	–0.0549**	–0.0703†	0.0660	–0.0580**	–0.0588	0.0558
$\mathbb{1}\{t \geq t^{est}\} \times (t - t^{est})$	(0.0669)	(0.0171)	(0.0235)	(0.0247)	(0.4261)	(0.0292)	(0.0401)	(0.0492)
French×Bureau Established				–0.3097**				–1.1944†
				(0.1478)				(0.3352)
French×#Years since BE				0.0297				–0.1323*
				(0.0311)				(0.0766)
Adj. R-sq	0.758	0.333	0.329	0.331	0.922	0.632	0.607	0.646
Sites	27	298	298	298	16	137	137	137
Observations	272	2,157	2,157	2,157	145	783	783	783
Site Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Restricted Sample	Yes	No	No	No	Yes	No	No	No
Treatment×Year Effects	No	Yes	No	No	No	Yes	No	No
Country Clustered S.E.	No	No	Yes (37)	No	No	No	Yes (31)	No
French Heterogeneous Effect	No	No	No	Yes	No	No	No	Yes

Notes: Significance levels: *0.10, **0.05, and †0.01. The dependent variable and all covariates are expressed in logs. All estimations use cluster-robust standard errors that are clustered on sites, except specifications (3) and (7), which uses country clustered standard errors.

Department of Economics, University of Alberta
Working Paper Series

2015-03: On the Optimal Design of Demand Response Policies – **Brown, D.,** Sappington, D.

2015-02: Fiscal Transparency, Measurement and Determinants: Evidence from 27 Developing Countries – Tehou, T. Y., **Sharaf, M.**

2015-01: Trends in Earnings Inequality and Earnings Instability among U.S. Couples: How Important is Assortative Matching? – **Hryshko, D.,** Juhn, C., McCue, K.

2014-13: Capacity Payment Mechanisms and Investment Incentives in Restructured Electricity Markets – **Brown, D.**

2014-12: On the Optimal Design of Distributed Generation Policies: Is Net Metering Ever Optimal? – **Brown, D.,** Sappington, D.

2014-11: Output Growth and Commodity Prices in Latin America: What Has Changed? **– Fossati, S.**

2014-10: A Survey of the Economics of Patent Systems and Procedures – **Eckert, A., Langinier, C.**

2014-09: Using Bayesian Imputation to Assess Racial and Ethnic Disparities in Pediatric Performance Measures – **Brown, D.,** Knapp, C., Baker, K., Kaufmann, M.

2014-08: Effects of an Integrated Care System on Children with Special Heath Care Needs' Medicaid Expenditures – Marcu, M., Knapp, C., Madden, V., **Brown, D.,** Wang, H., Sloyer, P.

2014-07: The Effect of Subsidized Entry on Capacity Auctions and the Long-Run Resource Adequacy of Electricity Markets – **Brown, D.**

2014-06: The Impact of Place-Based Employment Tax Credits on Local Labor: Evidence from Tax Data – Tong, P., **Zhou, L.**

2014-05: The Louis-Schmelling Paradox and the League Standing Effect Reconsidered – Humphreys, B., **Zhou, L.**

2014-04: Urban Casinos and Local Housing Markets: Evidence from the US - **Huang, H.,** Humphreys, B., **Zhou, L.**

2014-03: Loss Aversion, Team Relocations, and Major League Expansion **–**Humphreys, B., **Zhou, L.**

2014-02: Do Urban Casinos Affect Nearby Neighborhoods? Evidence from Canada – **Huang, H., Humphreys, B., Zhou, L.**

2014-01: Rule-Based Resource Revenue Stabilization Funds: A Welfare Comparison – **Landon, S., Smith, C.**

2013-13: The Distributional Impacts of an Energy Boom in Western Canada – **Marchand, J.**

2013-12: Privatization in China: Technology and Gender in the Manufacturing Sector – Dammert, Ana C., **Ural-Marchand, B**.

2013-11: Market Structure, Imperfect Tariff Pass-Through, and Household Welfare in Urban China – Han, J., Runjuan L., **Ural-Marchand, B.,** Zhang, J.

2013-10: Shotgun Mechanisms for Common-Value Partnerships: The Unassigned-Offeror Problem – **Landeo, C.,** Spier, K.

2013-09: Irreconcilable Differences: Judicial Resoluton of Business Deadlock – Landeo, C., Spier, K.

2013-08: The Effects of Exchange Rates on Employment in Canada – **Huang, H.,** Pang, K., Tang, Y.

2013-07: How Did Exchange Rates Affect Employment in US Cities? – **Huang, H.,** Tang, Y.

2013-06: The Impact of Resale on Entry in Second Price Auctions – **Che, X**., Lee, P., Yang, Y.

2013-05: Shotguns and Deadlocks – **Landeo, C.,** Spier, K.