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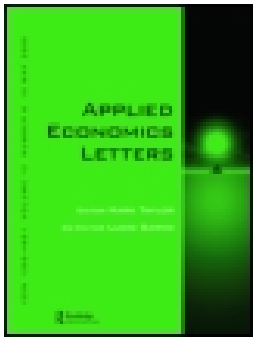
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Does legal system matter for directed technical change? Evidence from the auto industry

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ABSTRACT

Does the effect of fuel taxes on clean innovations (e.g. hybrid technology) depend on the legal system's rigidity? Using 1986–2005 data from more than 1900 firms, evidence suggests that auto-industry firms located in civil law (with more rigid laws) countries increase clean technology patenting more than common law (with more flexible laws) firms when the tax-inclusive fuel price rises. A rigid legal system appears to raise clean technology innovation.

KEYWORDS

Innovation; clean technology; directed technical change; legal origin; energy policy

JEL CLASSIFICATION

O31; K49; Q58; Q48

I. Introduction

Climate change is a major public policy issue. Technological innovation encouraged by government tax policy (directed technical change) is a possible response (Acemoglu et al., 2012). Aghion et al. (2016) (hereafter, ADHMY) show that auto firms patent more clean technologies when the encounter higher tax-inclusive fuel prices. They also document path-dependence in innovation due to other firms' and own prior innovation history. Anderlini et al. (2013) argue that legal institutions influence the speed of technical change due to different levels of flexibility.

We study how the legal regime influences innovation, in particular auto firms' clean technology innovation-responses to tax-inclusive fuel price movements, a topic largely ignored by the empirical literature. Our analysis should help predict the impact of directed technical change in countries with different legal systems. Beck, Demirgüç-Kunt, and Levine (2003), for example, argue that common law is more flexible than civil law, and we focus on these two systems.

Anderlini et al.'s theory compares a flexible legal regime, where rules and penalties may be altered after innovation occurs, to a rigid legal system without any changes. A trade-off emerges between commitment and flexibility, and a time-inconsistency problem may arise. A flexible system may provide stronger incentives for innovation *ex ante*, but *ex post* lawmakers may choose

policies that are less favourable for the innovator. For example, innovations that yield lower fuel consumption and CO₂ emissions may spur lawmakers to change regulations or taxes *ex post*. This reduces the incentive to innovate. Anderlini et al. argue that rigid legal regimes reduce uncertainty regarding future legislation and encourage research and development (R and D) investment in early stage technologies. Comin and Hobijn (2009) argue that where legislative flexibility is high, new technology adoption is slower because old-technology firms may more easily lobby against new technologies. We note also that civil law has been shown to yield worse regulatory, judicial, financial, and economic outcomes, supporting the Legal Origins Theory by La Porta, Lopez-De-Silanes, and Shleifer (2008) (see also, e.g. Botero et al. 2004). This may lower the expected profitability of innovation in civil law countries. However, Fredriksson and Wollscheid (2015) report that civil law countries set stricter climate change regulation, which may increase the rate of clean technology innovation in those countries. In sum, the expected effect of legal system on clean technology innovation is ambiguous, and thus the relationship needs to be resolved empirically.

We use firm-level panel data on patenting of clean innovations (e.g. hybrid or electric) in the auto industry, and dynamic count data Poisson models. Our evidence suggests that the response to directed

Table 1. Descriptive statistics.

	French civil law countries			Common law countries		
	Mean	Min	Max	Mean	Min	Max
Fuel price USD	0.822	0.349	1.720	0.758	0.349	1.795
R and D subsidies Mn USD	1.290	0.020	6.252	2.235	0.020	6.252
Emission regulation	1.945	0.263	20.707	1.913	0.263	21.522
Clean spillovers	38.346	0.003	278.857	65.641	0.012	559.290
Dirty spillovers	178.287	0.165	1371.485	247.836	0.202	1370.158
Own stock clean	0.955	0.002	30.848	0.990	0.002	48.360
Own stock dirty	0.829	0.001	46.816	0.864	0.001	59.504
Observations		9940			28,580	

technical change is greater under rigid legal regimes, that is, in civil law countries.

II. Empirical method

To estimate the number of clean patents deposited by a firm, we adopt ADHMY's data and empirical specification:

$$\begin{aligned}
 PAT_{it} = & \exp(\beta_1 \ln FP_{it-1} + \beta_2 \ln SPILL_{C,it-1} \\
 & + \beta_3 \ln SPILL_{D,it-1} + \beta_4 \ln K_{C,it-1} \\
 & + \beta_5 \ln K_{D,it-1} + \beta_w \ln w_{it} + T_t) \eta_i + \mu_{it},
 \end{aligned} \quad (1)$$

where PAT_{it} is the number of clean patents deposited by firm i in year t , and FP_{it-1} is the tax inclusive fuel price faced by firm i in year $t - 1$. Since innovation is a path-dependent process, we include firms' stocks of clean and dirty patents (K_C and K_D , respectively). We control for the number of patents deposited by firms located in the same geographical area ($SPILL_C$ and $SPILL_D$), recognizing that firms build on neighbours' knowledge. w_{it} represents additional control variables, T_t year dummies, η_i is firm conditional fixed effects, and μ_{it} is the error term. We estimate Equation (1) for countries with rigid (civil law) and flexible (common law) legal systems, respectively.

To address endogeneity in dynamic firm-level fixed-effects Poisson models, Blundell, Griffith, and Van Reenen (1999), henceforth BGV, develop a control-function fixed-effect estimator.¹ They condition on the pre-sample average of the dependent variable to proxy out the fixed effect. Our dataset may not possess the long pre-sample history of realizations of the dependent variable necessary to implement the BGV estimator; green patenting occurs mainly towards the

end of the sample period. ADHMY propose using a control-function fixed-effects estimator (CFX) to deal with the fixed effect. They simultaneously estimate the main regression equation and a second equation allowing identification of the control-function from future data. We implement their novel technique but utilize the BVG estimator as a robustness check.

III. Data

With 1986–2005 firm-level data from ADHMY, we focus exclusively on 'triadic' clean patents (approve by the European, Japanese, and US patent offices) for firms headquartered in common law and French civil law countries, respectively. Using triadic patents eliminates patents of very low value.

To estimate the effect of directed technical change on clean innovation, we utilize the logarithm of fuel price data (average of diesel and gasoline prices) from 25 major countries compiled by ADHMY. The firm-specific fuel price index equals $\ln FP_{it} = \sum w_{ic0}^{FP} \ln FP_{ct}$, where FP_{ct} is the tax-inclusive fuel price, and w_{ic0}^{FP} is the firm-specific weight based on the fraction of firm i 's patents (clean and dirty) granted in country c during 1965–1985. According to this specification, firms secure patents where they expect future sales. Using weights based on the patent portfolio of each firm averaged over the 1965–1985 (pre-sample) period ensures that the weights are weakly exogenous, as patent location could be influenced by shocks to innovation.

We divide the sample based on whether firms are headquartered in French civil law (497 firms) or common law (1429 firms) countries (La Porta, Lopez-De-Silanes, and Shleifer 2008).² We focus on these two legal systems because they present the sharpest contrast in terms of jurisprudence and flexibility (see Beck,

¹The firm's own stock of patents is included among the regressors.

²Common law countries included: Bermuda, Hong Kong, Belize, Dominica, Thailand, Singapore, South Africa, Israel, UK, Australia, India, USA, Ireland, Sri Lanka, Cayman Islands, New Zealand, Barbados. French civil law countries included: Peru, Netherlands, Turkey, Italy, Belgium, France, Indonesia, Brazil, Luxembourg, Russia, Netherlands Antilles, Greece, Venezuela, Argentina, Mauritius, Malta, Spain.

Demirgüç-Kunt, and Levine 2003). During the time period studied, clean technology was relatively new and firms faced uncertainty regarding the location of future sales, so ‘home bias’ should make local legal institutions particularly important. We therefore take the view that only one legal system matters for each firm’s R and D decision.³

We control for patent stock, calculated using the perpetual inventory method (Peri 2005): $K_{z,it} = PAT_{z,it} + (1 - \delta)K_{z,it-1}$, where $z \in \{Dirty, Clean\}$, and $\delta = 0.20$, following the literature. We control for firm-specific spillover pools of knowledge, calculated for firm i as $SPILL_{z,it} = \sum_c \omega_{ic0}^S SPILL_{z,ct}$, where ω_{ic0}^S is the share of all firm i ’s inventors in country c during years 1965–1985, and $SPILL_{z,ct} = \sum_{j \neq i} \omega_{jc0}^S K_{z,jt}$ is the spillover pool in country c at time t , that is, it is the sum of all other firms’ patent stocks weighted by the number of inventors those firms have in that country.⁴ See Table 1 for descriptive statistics.

IV. Empirical results

Table 2 reports estimations of Equation (1). Panel A reports estimations using the flow of clean patents in firms headquartered in French civil

law countries only. Panel B shows the corresponding estimations but using common law country data only. Models (1)–(3) and (5)–(7) show CFX estimator results; Models (4) and (8) report BGV estimator results. Models (2)–(3) and (6)–(7) include a measure of public R and D subsidy expenditures on energy efficiency in transportation (Mn USD 2010 prices; IEA 2015). Models (3) and (7) add a measure of automobile tailpipe emission regulations (Dechezleprêtre, Neumayer, and Perkins 2015). Regarding the R and D subsidy expenditures measure, the inventor’s country of residence is used, similarly as for the knowledge spillover variables. The measure of emission regulation is built using the same weights as the fuel price variable. These two controls are important as they are alternative ways (other than fuel taxes) for governments to direct technical change.

Comparing patenting by firms headquartered in civil law versus common law countries, we find that while the coefficient on the fuel price is positive and significant in both groups of countries (disregarding Model (1), where *Fuel Price* is insignificant), it is substantially larger in civil law countries. Models (3) and (7), for example, indicate that the fuel price elasticity is 2.321 in civil

Table 2. Directed technical change and legal heritage.

Estimator	Panel A Civil law countries				Panel B Common law countries			
	(1) CFX	(2) CFX	(3) CFX	(4) BGV	(5) CFX	(6) CFX	(7) CFX	(8) BGV
Fuel price	1.812 (1.487)	2.346* (1.315)	2.321* (1.305)	1.559** (0.655)	1.106** (0.504)	1.214** (0.522)	1.195** (0.524)	1.067*** (0.384)
R and D subsidies		−0.065 (0.127)	−0.110 (0.140)			0.017 (0.096)	0.020 (0.095)	
Emission regulation			−0.475 (0.298)				0.031 (0.434)	
Clean spillovers	0.587*** (0.193)	0.596*** (0.227)	0.715*** (0.219)	0.589** (0.233)	−0.167 (0.145)	−0.174 (0.174)	−0.174 (0.170)	0.324** (0.163)
Dirty spillovers	−0.420*** (0.157)	−0.438*** (0.159)	−0.489*** (0.157)	−0.447** (0.197)	0.307** (0.151)	0.305** (0.142)	0.302** (0.141)	−0.210 (0.136)
Own stock clean	0.422*** (0.072)	0.440*** (0.105)	0.429*** (0.100)	0.800*** (0.075)	0.541*** (0.056)	0.583*** (0.059)	0.583*** (0.059)	0.967*** (0.054)
Own stock dirty	0.374*** (0.048)	0.350*** (0.053)	0.380*** (0.052)	0.266*** (0.065)	0.281*** (0.038)	0.297*** (0.040)	0.297*** (0.040)	0.138** (0.068)
Observations	9940	9940	9940	9940	28580	28580	28580	28580
Firms	497	497	497	497	1429	1429	1429	1429

Dependent variable is clean patent flow. Standard errors in parenthesis are clustered at the firm level. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

³Another option involves assigning a percentage of expected sales in common and French civil law countries, as with fuel prices. However, this option is unfeasible due to data and parameter interpretation problems. Fuel price data lack satisfactory availability outside the 25 countries used by ADHMV in the fuel price construction. Furthermore, interpreting interacted variable coefficients with the ADHMV estimator is clearly beyond the scope of this article.

⁴See Appendix C, ADHMV, for a complete description of the variables’ construction.

law countries while it is 1.195 in common law countries. The Welch t -statistic (a generalization of the student t -test used to compare regression coefficients fitted to independent datasets (Welch 1947)) rejects the null hypothesis of no statistical difference between *Fuel price* coefficients: Model 2 vs. 6 (Welch t -statistic 83.6); Model 3 vs. 7 (83.7); Model 4 vs. 8 (49.6). Using the insignificant *Fuel price* coefficient in Model (1) for comparisons is not meaningful. The results do reveal the importance of controlling for R and D subsidies, which are aimed at influencing innovation incentives.⁵ Rigid law with lower uncertainty regarding future legislation appears to encourage clean technology innovation.

Firms' own stocks of clean and dirty patents, as well as other local inventors' such stocks, tend to affect patenting. This is consistent with innovation being a path dependent process and that innovators build on the existing own and local colleagues' stocks of knowledge.

V. Conclusion

Consistent with recent theoretical work, our evidence suggests that the rigidity of legal systems affects the innovation response to directed technical change. Clean technology patenting is more responsive to changes in tax-inclusive fuel price changes in civil law countries (more rigid legal systems) compared to common law countries (relatively flexible legal systems). Legal regimes thus have implications for the feasibility of addressing climate change through inducing technological innovation through market-oriented policies.

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⁵See also ADHMV.