The Light at the End of the Tunnel: The Impact of Policy on the Global Diffusion of Fluorescent Lamps

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Abstract

The objective of this paper is to evaluate the effectiveness of different policies in facilitating the diffusion of green innovations through trade. Focusing on developing countries, I develop a theoretical framework in which to analyse the effectiveness of policies such as information, subsidies, and banning the use of the incumbent technology in encouraging the use of a clean technology. The empirical model uses a novel dataset of a sample of 72 low and middle-income countries, spanning the period 1993- 2013 to evaluate the effectiveness of these policies, and analyse the determinants of policy choice. Results suggest that domestic policies pay a pivotal role in facilitating the transfer of CFL, especially subsidies; however, simultaneous implementation of policies need not necessarily be effective. Moreover, countries learn from the experiences of other countries in deciding whether to implement a particular policy. The paper also finds a role for trade policy instruments, such as trade agreements with top exporters, to facilitate clean technology diffusion.

Keywords: International Trade; Policy Effectiveness;Technology Diffusion.

JEL Codes: D78;D83;F13;H30;O33;O38;Q48.

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1 Introduction

It is widely accepted that policy-makers should formulate climate-change mitigation strategies that incorporate multiple policy instruments (or one per market failure) for reducing greenhouse gas emissions to meet global obligations (such as those mandated by the Kyoto Protocol). An important source for achieving these reductions in emissions is improving the energy efficiency of electrical appliances that are used by households, which may not only reduce energy consumption, but can also achieve cost-savings for households.

Energy-efficient lighting is an example of an area where significant opportunity for these reductions lies. In 2005, lighting accounted for 2650 TWh, or approximately 19% of global electricity use per annum: it was also responsible for 8% of global CO_2 emissions, which is equivalent to about 70% of total emissions from all passenger vehicles in the world (Lefèvre et al., 2006). As the population burgeons in the developing world, carbon-dioxide emissions can be expected to increase. Improving the energy efficiency in lighting is thus an important (and arguably, relatively simple) way to reduce energy use, at least in the short run.

The objective of this paper is to evaluate the effectiveness of policies implemented by governments in encouraging the diffusion of a clean lighting technology (CFL, or compact fluorescent lamps) into developing countries that are not large producers of these bulbs. The analysis focuses on the role of information policies (such as labelling schemes and awareness campaigns), price incentives (such as subsidies and free CFL distribution schemes), and a ban on the import (or sale) of IB in facilitating imports of these lamps. The paper develops a theoretical framework, and conducts an empirical estimation using data from 72 low and middle income countries from 1993 to 2013.

There have been several improvements in lighting technologies in recent times. The traditional lighting technology has been that of incandescent bulbs (IB), also called general service lighting (GLS).[1]. Energy-efficient CFL have potential to generate residential energy savings, on average consuming 20-25% of the energy used by IB, for providing the same amount of light (Lefèvre et al., 2006). The life-span of a CFL is much higher than that of an IB: the average IB has a life of

[1] .An IB "produces light when an electric current passes through a filament and causes it to glow", whereas a CFL "produces light when an electric arc passes between cathodes to excite mercury and other gases producing radiant energy, which is then converted to visible light by a phosphor coating" (ALA, 2199)

about 1000 hours, compared to 5000-25000 hours for the CFL (Lefèvre et al., 2006).[2]

Despite several benefits of using CFLs, their uptake has been limited. CFLs only accounted for about 6% of the world lighting market in 2006 (Lefèvre et al., 2006). A significant hurdle has been the high initial cost of these bulbs compared to IBs. However, it appears that a lack of affordability is not the only factor dissuading consumers: Allcott and Taubinsky (2015) conduct two randomized control trials in the US, that aim to provide consumers with information about the energy costs of different light bulbs. They find that CFLs and IBs are imperfect substitutes. Their key results are that while consumers benefit from subsidies, and from minimum energy performance standards, these are only second-best policies. They find that effective information dissemination remains the most potent policy, given that uncertainty about the lamp life is a significant deterrent towards their greater adoption.

There is already a broad theoretical literature that looks at the role of policy instruments in incentivising firms to switch to using cleaner technologies; Jaffe and Stavins (1994) build a theoretical model to understand the "energy paradox", or the limited adoption of energy-saving technologies by firms. They attribute the slowness of clean technology diffusion to information asymmetries, private information costs, high discount rates, and heterogeneity among potential adopters. In this paper, some of these factors (in particular private costs and lack of information) are found to be important deterrents for greater CFL adoption amongst consumers as well. Requate and Unold (2003) find that for an individual firm, it is not immediately clear that price instruments are more effective than command-and-control policies in the adoption of abatement technologies, and that the relative superiority of different policy instruments depends on whether regulators are able to anticipate the development of new technologies. In this paper, I attempt to rank the policies based on effectiveness, and find that for consumers in developing countries, price instruments are most effective.

The theoretical model developed that I develop focuses on the role of policies in directly encouraging consumers (rather than firms) to adopt a clean technology, and analyses the factors that may influence policy choice of policy-makers. I develop a theoretical framework, which is loosely based on a model of innovation diffusion across heterogeneous agents developed in Young (2009).

[2] .The current technology frontier though is represented by the light-emitting diodes (LEDs), which are even more energy efficient than CFLs.

The framework predicts the decision of a consumer to adopt a technology based on its costs and benefits, like the class of Probit models developed in the diffusion literature, which attribute the slowness of the diffusion process to heterogeneity between agents (Geroski, 2000)).[3]

In the empirical part of this paper, I study the effectiveness of different policy instruments, both when implemented in isolation, and in conjunction with other policies. An instrumental variable two-stage least squares (IV-2SLS) estimation is used to study this, where the endogenous policy variables are dummy variables which indicate the presence of a policy in a given country, in a given year. The measure of diffusion used in this paper is imports of CFL, as the countries in the sample are not major producers of these bulbs. The use of imports as a measure of CFL diffusion yields the familiar S-shaped diffusion curve, which is a common finding in the empirical literature.[4]

The empirical literature on the role of policy instruments in encouraging technology diffusion is very broad, and comprises both cross-country analyses, and county-specific studies. Comin and Hobijn (2004) introduce a novel historical cross-country dataset to study diffusion of various technologies, and find that technologies are first adopted by advanced economies, and subsequently by countries that are relatively less developed. Moreover, it may take a long time before a technology starts dominating its predecessor. These findings support the general observations that CFL use lags behind in developing countries (compared to that in developed countries), and that consumers have been reluctant to switch from IB to CFL. Johnstone et al. (2010) looks at the effect of environmental policies on innovation across countries in five different renewable energy technologies, using patent applications as a proxy for innovative activity. This paper is akin to Johnstone et al. (2010) in capturing the effect of (heterogenous) policies. Bosetti and Verdolini (2013) also use policy dummies to look at the diffusion of both renewable and fossil-fuel based technology in the power sector. They use a dynamic panel to test the effectiveness of different policies, in order to deal with possible endogeneity of these variables.

Comin et al. (2012) find a role for distance from adoption leaders in explaining the slow adoption of technologies. However, they also find that the effect of distance diminishes over time,

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[3] .The most commonly used models of diffusion in the literature are the epidemic models, which developed in the 1950's. Geroski (2000) provides an exhaustive descriptive summary of diffusion models, including these epidemic models.

[4] .Griliches (1957), Mansfield (1961) and Mansfield (1968) were some of the first papers which studied the diffusion patterns of hybrid corn in the US, and of several industrial innovations respectively, and derived the "logistic curve" synonymous with diffusion.

and eventually disappears. In this paper, I utilise the spatial differences in policy adoption (rather than in the adoption of the CFL technology itself) in constructing the instrumental variable for the (endogenous) policy variables that are used in the IV-2SLS estimation. I build on the assumption that distance to (policy) adoption leaders matters, and that countries "learn" from the experiences of other (near) countries in deciding which policies to implement.

This approach has been adopted in the literature: Guasch et al. (2003), for instance, use the presence of contractual clauses in other countries to instrument for the presence of a contractual clause in a certain country, and its consequent impact on rates of contract renegotiation in the infrastructure sector in Latin American countries. This is also found in the literature on spatial spillovers in fiscal policy choices; Keen and Lockwood (2010) use the assumption that the adoption of value-added tax (VAT) in a country depends on its adoption in neighbouring countries. Ebeke and Ngouana (2015) use energy subsidies in neighbouring countries to instrument for energy subsidies in a sample of low income countries.

Reppelin-Hill (1999) posited that the trade openness of an economy may play a role in the global diffusion of electric-arc furnaces (EAFs) in the steel industry. She finds that EAF technologies are adopted faster in countries with more open economies. I use a more specific measure of whether a country is open to trade in CFL (namely, whether the country has entered into a trade agreement with a top exporter of CFL in a given year), and find that it is also a determinant of diffusion.

In this paper, I also study for possible complementaries between policies; there are other country-level studies which look at the role of different policies in encouraging new technology adoption, and also study their complementarity, especially in health economics. Ashraf et al. (2013) conduct a field experiment in Zambia encouraging households to buy a health product, and find that information policies and subsidies are complementary to each other, i.e. the presence of information policies renders subsidies effective in encouraging purchase of these products. However, to my knowledge, there is no study which looks at the complementarity of different policies in encouraging clean technology adoption.

The main results of the paper are that each of the policy options considered in this paper are effective in ensuring greater CFL adoption in this sample of countries, with subsidies being the most effective. The paper also finds that the effectiveness of these policies, and the choice of a policy-maker to implement them, depends strongly on how effectively the policy-maker can implement these policies, and on what scale. I also provide some evidence to suggest that countries mimic the behaviour of their neighbours in adopting clean technologies, and finally find that trade agreements between countries and exporters of CFL play an important role in its greater diffusion.

This paper makes three main contributions to the literature on the impact of policy on clean technology diffusion: the first is its focus on low and middle income countries . Given that this is the sample of countries where opportunities for cheap abatement lie, it is critical to understand which policies are effective in lower-income countries. Most of the current literature on the impact of policy on clean technology adoption uses data from experiments (or surveys) implemented in developed countries. [5] This is the first paper, to my knowledge, which uses data from a cross-section of developing countries.

The second main contribution of this paper lies in the creation and use of a novel data set to evaluate the usefulness of different policy options in encouraging the diffusion of CFL. The presence or absence of these policies has been coded using information provided in the United Nations Environmental Programme (UNEP) Country Policy Map (UNEP, 2014) as a part of their en.lighten Initiative, which provides extensive information on the current status of clean lighting adoption in several countries, along with a list of the policies that have been adopted to encourage greater use of CFL.

The final contribution of this paper lies in its findings about possible complementarity of these policies when implemented together, and thus a possible implication on the sequencing of policies in developing countries to ensure clean technology adoption. To my knowledge, this is the first paper to infer about the complementarity of policy instruments in encouraging clean technology diffusion.

The structure of the paper is as follows: section 2 builds a theoretical framework, section 3 explains the data and methodology used for the empirical analysis, and it also includes the empirical results, section 4 provides the policy implications, while section 5 concludes.

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[5] .Allcott and Taubinsky (2015) use data from two randomized control trials in the US, while Mills and Schleich (2010) look at the barriers to a household looking to adopt CFL, using German survey data.

2 Theory

This section develops a theoretical framework to build hypotheses that are tested in the empirical model. The objective is to understand both the conditions under which governments would adopt certain policies, and the effectiveness of these policies. The hypotheses developed in this section will be tested in the empirical part of the paper.

It would be ideal to model the decision of a policy-maker to choose policy instruments by minimising the expenditure on the policies, subject to meeting a target adoption threshold. However, that approach has not been adopted in this paper. It is more appropriate to look at conditions in favour of choosing an instrument, given the nature of data used for empirical estimation. Moreover, it is not very clear how variables such as "precision with which information can be provided" or "the effectiveness with which a ban can be enforced" are quantifiable. For these reasons, the paper develops a theoretical framework which can yield predictions that are testable with the data that is available.

This model builds on the framework that Young (2009) develops to study the process of social learning across heterogeneous consumers. In his model of social learning, consumers observe the behaviour of previous adopters before deciding whether an innovation is worth adopting. The decision of an individual to adopt a new technology depends on his prior beliefs about the payoff gain from switching to it, the amount of information he receives about the product, and his costs of adoption. The model that I develop in this paper retains the latter assumptions, but does not dwell on the former, i.e. I focus on the role of policy in influencing adoption decision of consumers. The primary reason for this is that in the empirical analysis, I test the propositions developed in this section using macro-level data on diffusion of CFL into countries. While the data allows me to test for the effectiveness of different policies in influencing the diffusion of CFL in a country, it cannot be used to study learning across (possibly heterogenous) agents.

Much like the probit model used extensively in the technology diffusion literature (Geroski, 2000), the objective function of the consumers (or there constraints) are not explicitly modelled in this framework: it is assumed that consumers will adopt the technology if the benefits of doing so outweigh the costs. This simple structure is adopted instead of a full-fledged theoretical model, because it enables easy comparison between the results derived in this section, and those of the empirical estimation, where the decision to adopt a policy (first-stage of IV-2SLS estimation) and the effectiveness of the policy (second-stage) are modelled.

2.1 *General Framework*

Assume there are N consumers in the market. The problem of these consumers is to choose one of the two technologies, one energy-efficient (or clean), and the other energy-inefficient (or dirty). Every agent has identical prior beliefs about the benefits of switching to the new technology, but different costs of adoption, i.e. the source of heterogeneity is differences in the (relative) cost of adopting the new technology. The model retains the assumptions of Young (2009) such as observable payoffs, independence of payoffs across individuals and time periods, risk-neutrality and myopia of agents. Each consumer finds it in his interest to adopt this new technology if he believes that the innovation yields higher payoffs than the technology that he is currently consuming.

The payoff from adopting the innovation is a random variable X following the normal distribution with mean μ and variance σ^2, which is i.i.d. among both agents and time periods. In this context, X has the interpretation of the cost savings per hour associated with the use of the clean technology compared to the use of one unit of the dirty technology, i.e. the (discounted) operating cost of the dirty technology minus the (discounted) operating cost of the clean technology. Each agent i has initial (identical) beliefs about the unknown mean payoff gain μ_0 and the unknown precision $\rho = \frac{1}{\sigma^2}$ such that for each value of ρ,the conditional distribution of μ is assumed to follow the normal distribution with mean μ_0 and precision $\rho\,\tau$ (standard normal-normal updating process ((Young, 2009),(DeGroot, 1970))). A low value of τ implies flexibility of beliefs about this mean payoff, i.e. the requirement of relatively little evidence to convince consumers about the payoff gain from consuming the clean choice (consumers are willing to update their beliefs quite easily). A low value of μ_0 reflects pessimism about the mean payoff gain (or cost savings) from consuming the clean choice. Let C_{it} be the random variable denoting the cost of adoption for consumer i in period t, with c_i denoting a particular value of this variable.

Initially, if the myopic consumer i believes that the mean payoff (gain) is less than the cost of adoption, i.e.

$$\mu_0 \leq c_i \tag{1}$$

then he will not adopt the technology. Denote μ_0 as the initial "adoption threshold" c^*. This represents the maximum (relative) cost of CFL adoption that can convince a consumer to still use the technology, in the absence of any policies.

In the model, C_{it} is assumed to be vary for each individual. It can be thought of as the sum of the price difference between the two lamps, and of idiosyncratic factors that limit consumers from purchasing CFL. Across the population, assume that c_{it} follows the normal distribution with mean 0 and variance σ_C^2, where c_{it} belongs to the interval [-α_C,α_C], i.e. it can be said that C_{it} conditional on -α_C<c_{it}<α_C has a truncated normal distribution. Let F(c) denote the (normal) cumulative distribution function of C_{it}. Assume that c^* is less than or equal to α_C.

Consider a period t up to which consumer i has not begun using the clean choice. The model takes the mean beliefs, μ_0 and the flexibility of beliefs, τ, as given by this period i..e policies will not have a role in changing these. It is clear that the consumers who choose to adopt the clean technology in the absence of any policy imposed by the social planner in period t will be the ones for whom the above condition 1 holds.

2.2 *Policy Instruments*

The goal of the policy-maker in this model is to implement policies to ensure that consumers are motivated to buy CFL. There are three policy instruments to do this: information provision, subsidies and a ban on IB. Let the damages (measured in monetary terms, denoting the adverse effects in terms of climate change from IB use) from the use of IB be denoted by D (assume that there are no damages from CFL use). Denote the adoption threshold that the policy maker targets by c_T, i.e. policies will be implemented to ensure that all consumers with costs less than or equal to c_T switch to CFL. Assume that the policy-maker wants to achieve full conversion to CFL, so that he would set $c_T = \alpha_C$. Also, assume that the policy maker has $\bar{T}$ of resources to implement these policies, i.e. the total expenditure on policies cannot exceed $\bar{T}$.

2.2.1 *Information Provision*

The first type of policy the policy-maker can implement is information provision. The type of information policy being envisioned in this model could be either a mandatory or voluntary labelling scheme, or an awareness campaign to inform consumers about the energy efficiency properties of the lamp. While the onus of printing labels typically falls on firms, it is foreseeable that governments have enforcement mechanisms to ensure that firms abide by the policies, and certification duties to check that information is accurately provided.

A vast literature exists on the role of information labels in motivating consumers to consume energy-efficient household appliances, with the objective of solving the market failures of imperfect information and bounded rationality that often prohibit consumers from using these appliances. Newell and Siikamaki (2014) use experimental data to conclude that providing consumers information on the monetary value of their savings in terms of purchase price, or present value operating costs of using an appliance, is indeed effective in encouraging consumers to invest in energy-saving technologies. Ward et al. (2011) provide evidence of the effectiveness of Energy Star consumer labels in influencing consumer purchase decisions of refrigerators in the US, and find that their willingness to pay for products certified by these labels was influenced by the energy savings they received, but it was also driven by environmental benefits of their action. Teisl et al. (2002) study the effectiveness of "dolphin-safe" labels in the purchases of tuna, and find that there are inter-temporal differences in the magnitude of this effectiveness; namely, the effectiveness of the label on he number of purchases is slow just after the introduction of the label, but then it hastens as the flow of information improves, following the S-shaped diffusion curve often observed in the technology diffusion literature.

In this model, the policy-maker needs to decide whether to introduce a labelling scheme for CFL in a given period in terms of the cost of its implementation, and the benefits in terms of the number of consumers who will be motivated by the information campaign to switch to CFL.

Consider a labelling scheme that the policy-maker implements in period t, where he informs consumers about the benefit of switching to CFL. Assume that the information about the potential payoff gain from CFL use is provided in the form of a signal X', which is normally distributed with mean μ and variance σ_L^2, where $\sigma_L^2 \leq \sigma^2$; consumers can then update their beliefs about the payoff gain from CFL.

The new value of μ_t after the information is provided in period t can be derived (by using normal-normal sequential Bayesian updating) as

$$c^{**} = \frac{\sigma^2 \mu + \tau \sigma_L^2 \mu_0}{\sigma^2 + \tau \sigma_L^2} \tag{2}$$

Here, c^{**} denotes the adoption threshold with information provision. It can be shown that c^{**} is greater than c^{*}, which implies that F(c^{**}) is also greater than F(c^{*}). This implies that information provision should be effective in encouraging consumers to switch from using IB to CFL. However, the size of this increase depends on the variability of the information signal provided, i.e. σ_L^2; if information is provided with greater precision, $\tau\sigma_L^2$ is low, and c^{**} is high, implying more consumers will switch to CFL. The share of CFL adoption with information provision is given by F(c^{**}).

The decision to adopt this policy also depends on the cost of its implementation. Assume that this cost, represented by F_I, is fixed i.e. it does not depend on the precision with which information is provided in the label, and it is also independent of the number of users of CFL. In addition, the policy-maker will also have to incur costs associated with the environmental damages from IB consumption: assume that the damages from use of an IB are given by D in monetary terms (and the damages from CFL use are zero). The total cost of providing information can be represented as

$$Cost_I = F_I + N(1 - F(c^{**}))D \tag{3}$$

It is clear from expression 3 that the cost of providing information to consumers is decreasing in the precision with which information is provided, because F(c^{**}) is increasing in it.

2.2.2 *Subsidy*

The second policy option available with the social planner is to subsidise CFL. In the framework developed so far, a subsidy reduces the costs of adoption for the entire population symmetrically, i.e. reduces c_{it} for all i. This increases the likelihood of all consumers to adopt CFL. Assume that a uniform subsidy of s is applied by the policy-maker on the price of CFL, which makes the cost of adoption for all consumers c_{it}-s. Thus, the fraction of the population that will now adopt CFL are those i for whom c_{it}-s is less than or equal to c^*; the corresponding share of CFL adoption given by F(c^*+s). The proportion of population using CFL is thus monotonically increasing in the size of the subsidy.

The cost of the subsidy to the social-planner can be represented as the total subsidy amount that is distributed to all consumers (not just those who are switching to CFL) plus the associated environmental damages from consumers who continue using IB. This can be given by the following expression:

$$Cost_S = Ns + N(1 - F(c^* + s))D \tag{4}$$

2.2.3 *Ban on IB*

The third policy instrument available with the social planner is a ban on the sale of IB. A ban on IB can be modelled as a decrease in the costs of CFL adoption c_{it} for all i: once consumers are forced to buy CFL, the cost of acquiring IB increases, which implies that the relative cost of CFL adoption, c_{it}, decreases. Let a denote the effectiveness with which the ban is enforced, where $0 < a \leq 1$. The lower is a, more strictly the ban is enforced. Thus, the consumers that now switch to CFL are those for whom $ac_{it} \leq c*$. The corresponding share of CFL adoption is $F(\frac{c*}{a})$.

The cost of the IB ban is equal to the cost of enforcing the ban plus the damages associated with continued use of IB. Let C(a) denote the enforcement costs of the ban on IB. Assume that $C'_a<0$ and $C''_a>0$; the cost of the ban is increasing in the level of enforcement. The total costs of implementing this policy are given by

$$Cost_B = C(a) + N(1 - F(\frac{c^*}{a}))D \tag{5}$$

2.3 *Choice of Policy Instruments*

Given the shares of CFL adoption, and the costs associated with implementing the three policies, a policy-maker then must choose which instrument to use. In this section, the model takes as given the effectiveness with which policies can be implemented, the amount of subsidy disbursed, and the initial beliefs of the consumers. The only choice variables of the model are the choices of policies by the policy-maker. The framework adopts this approach so as to corroborate with the empirical estimations: given the data on policy choice by governments, the theoretical model tries to explore what factors lead policy-makers to choose one policy over another (or even multiple policies at the same time). Based on the discussion of the previous subsections, we deduce (for the discussion that follows) that each of the three policy instruments are effective, when implemented in isolation. This leads to the proposition below:

Proposition 1 The three policy instruments are effective in increasing the share of CFL adoption amongst the population of consumers, however the magnitude of effectiveness of the three policies depends on exogenous factors such as how effectively policy-makers can enforce policies, and the size of the subsidy. Information provision is effective in encouraging consumers to switch if policy-makers can provide accurate information on the efficiency properties of CFL. Subsidies on CFL are effective if the size of the subsidy is large, and a ban on the use of IB is effective if the policy-maker is able to enforce the ban effectively.

2.3.1 *Conditions under which no policy is adopted*

There are two possibilities under which policy-makers may find it worthwhile not implement any policy at all: the first is when the initial beliefs of consumers are already optimistic, i.e. if c^* equals c_T. The second is that of the policy-maker being budget-constrained to implement even a single policy, which is more plausible given our focus on developing countries.

This will be the case if the costs given in expressions 3, 4 and 5 are all greater than $\bar{T}$. This is the case if the effectiveness with which policies such as the IB ban and information provision are implemented is very low, for instance, or the amount of subsidy needed is very high. In this case, the policy-maker is constrained to do nothing, and no policy is implemented at all (even if, given the policy parameters, the policies turn out to be effective).

Hypothesis 1 No policy will be implemented if the costs of adopting each of the policies are prohibitive: from expressions 3, 4 and 5, this will be the case if a) the policy-maker is unable to ensure provision of accurate information to consumers (i.e. σ_L^2 is high b) in case the size of the (exogenous) subsidy required (s) is too large, and c) the ban on IB (if implemented) is not enforced effectively, leading to large damages from continued use of IB by consumers (i.e. the second part of the expression in 5 outweighs the first).

2.3.2 *Determinants of policy choice*

Consider the choice of a policy-maker looking to implement policies to encourage CFL adoption: assume that the cost of implementing each of these policies is less than $\bar{T}$, so that at least one policy instrument is adopted. When would it make sense for a policy-maker to implement a particular policy?

Consider the net benefit to the policy-maker of information provision. Given that the share of CFL adoption becomes F(c^**), the benefit from its implementation is NF(c^**)X, where X is the random variable denoting the payoff gain from CFL use. The cost of its implementation is given by C_I in expression 3.Thus, the net benefit from implementing this policy is

$$B_I = NF(c^* *)X - F_I - N(1 - F(c^{**})D \tag{6}$$

Likewise, the net benefit from adopting subsidies, and the ban on IB can be derived as

$$B_S = NF(c^* + s)X - Ns - N(1 - F(c^* + s)D \tag{7}$$

$$B_B = NF(\frac{c^*}{a})X - Ns - N(1 - F(\frac{c^*}{a})D \tag{8}$$

where the expressions 4 and 5 have been used to substitute for C_S and C_B. Assume in this section that each of C_I, C_S and C_B is less than or equal to $\bar{T}$. Given the expressions for B_I, B_S and B_B derived above, the probability of choosing any policy instrument is the probability that the associated net benefit from its implementation is greater than or equal to zero. From 6, 7 and 8, these probabilities are

$$Prob(B_I \geq 0) = Prob(X \geq \frac{F_I + N(1 - F(c^{**})D}{NF(c^* *})) \tag{9}$$

$$Prob(B_S \geq 0) = Prob(X \geq \frac{Ns + N(1 - F(c^* + s))D}{NF(c^* + s)}) \tag{10}$$

$$Prob(B_B \geq 0) = Prob(X \geq (\frac{C(a) + N(1 - F(\frac{c^*}{a}))D}{NF(\frac{c^*}{a}))}) \tag{11}$$

X is normally distributed with mean μ and variance σ^2, which implies that we can use the normal CDF to derive expressions 9, 10 and 11.

Proposition 2

- Information provision is likely to be a policy instrument of choice for policy-makers, if the information can be provided accurately to consumers, i.e. if c^{**} is high. Even if the (fixed) cost of implementing this scheme is high, this would ensure that enough consumers switch to consuming CFL.

- Subsidies are likely to be adopted as a policy measure if the size of the subsidy is large. While this would increase the subsidy bill, the benefits from a larger proportion of the population switching to CFL would outweigh these costs (and those from damages related to continued use of IB).
- The ban on IB is likely to be adopted as a policy instrument, if the policy can be enforced effectively by the policy-maker, and the corresponding cost of enforcement C(a) is not too high.

This analysis abstracts from making predictions about the expenditure on implementing each of the policies, and the choice of the policy-maker in deciding between policy alternatives in the face of resource constraints. Given the exogenous policy parameters determining the adoption thresholds and the costs of policy implementation, it is not possible to predict the optimal policy choice unless more detailed data is available on the possible values of these parameters.

A useful extension of this framework would be to endogenise the policy parameters, and choose them to minimise the expenditure function of the policy-maker subject to meeting a target adoption threshold; the main constraint to this exercise is the availability of data that is consistent with testing the hypotheses developed in such a model.

2.3.3 *Choice of multiple policies*

It is entirely possible for a policy-maker in this framework to adopt multiple policies at the same time. This can be an effective measure to increase the share of CFL adoption, provided the policies are complementary, and do not undercut each other's effectiveness. In this section, the model looks at effectiveness of policy combinations, rather than the determinants of the decision to implement multiple policies.

Given the adoption thresholds derived for the policies in the previous sections, and the nature of increase in the share of CFL adoption through their implementation, it is clear that any two policies, when implemented together, will yield a higher share of CFL adoption than a single policy instrument would. However, since the increase is only measured in terms of the proportion of population that switches to CFL via the normal distribution F, for the effect to be significant, it must be the case that each of the policies are implemented effectively (which reverts to the results derived in Proposition 1).

This implies that while two policies (or even all three policies) when implemented in tandem may be ineffective in increasing the share of CFL adoption significantly beyond that which is possible using one policy, it is not possible for two policies in this framework to be substitutes. This means that it is not possible for the share of CFL adoption to fall after multiple policies have been implemented. This result is driven by no assumption being made on the sequence in which these policies are adopted.

3 Data, Methodology and Results

3.1 *Data*

In the empirical model developed in the next two subsections, I use cross-country data to study the effectiveness of the policy instruments discussed in the theoretical framework above, and the determinants of policy choice. The panel data focuses on lighting industry-specific policy adoption in a sample that includes 72 low and middle income countries, and spans 1993 to 2013. Table 6 (in the Appendix) presents the countries that are included in the data sample. The sample comprises six main geographic regions: the Middle-East, Caribbean/Latin America, Central Europe, South Asia, East Asia and Sub-Saharan Africa.

The countries included in the sample were chosen on the basis of availability of data on policies adopted, and if they were classified as low-income, lower middle-income or upper middle-income according to the World Bank 2014 classification. Due to concerns of possible sample selection, those countries were also included which have not enforced any policies.

The measure of diffusion used in the empirical estimation is the (logarithm of) the imports of CFL as a proportion of total imports of IB and CFL, measured in terms of weight (in tons). I follow Caselli and Coleman (2001) in using imports as a measure of diffusion. They use computer imports per worker as a measure of the cross-country diffusion of technology, and justify its use on the grounds that the computer industry is concentrated, with only a few countries providing most of the world's computer output. Technology diffusion in this case takes place through imports of the equipment embodying the technology. This argument is valid in this paper as well: the countries included in the data sample are not major producers of CFL, which implies that quantity of imports is a reasonable measure of their level of diffusion of CFL. Papageorgiou et al. (2007) also use real imports of medical equipment per capita as a measure of international medical technology diffusion. Another reason for the use of imports as a measure of diffusion is that it is difficult, if not impossible, to find data on consumption of lamps in the low and middle income countries included in the sample. Data on trade in lamps is obtained at the HS-6 digit level of classification from the UN COMTRADE database (UN, 2014).

Some of the bigger developing countries which export CFL are excluded from the sample, most notably China, which has accounted for almost 60-70% of exports of CFL in recent years. Other exporters such as Hungary, Indonesia and Thailand are also excluded. This is done to exclude countries with large production capabilities. Additionally, observations for which the ratio of value of imports to exports is less than 1 are also excluded.

The main independent variables of the model are the policy dummies, which are dummy variables to indicate the presence of a lighting-(in particular, CFL) specific policy in the country. These have been manually coded using information provided by UNEP, and from individual reports from countries electric utilities, governments, etc. These dummy variables are created to indicate the presence of voluntary/mandatory labels and awareness campaigns (i.e. the information provision policy of the government), price incentives such as subsidies, loans, tax rebates, and schemes for the free distribution of CFL and a ban on the use or import of IB. These policy variables take the value 1 in a certain period if the policy is implemented in the same period, and 0 otherwise.

These policies are the main instruments used by policy-makers in developing countries to encourage consumers to switch to CFL. The only notable exception is the imposition of minimum energy performance standards (or MEPS). While information on the use of these standards was also available in the UNEP database, this variable was found to be highly correlated with the dummy for information provision, and thus it has not been used in the empirical estimations [6]. This is because most energy labels printed on appliances such as light bulbs are required to display the energy performance standards that the product meets, which are often certified by local authorities.

Since the measure of diffusion used is imports of lamps, it is imperative to control for measures of trade policy in the empirical estimations. For instance, a trade agreement indicator is used for estimation, which takes the value 1 if the country is in a trade agreement with one of the top five

[6] .The pairwise correlation coefficient was found to be 51%

exporting countries of CFL in a given year (De Sousa, 2012). A variable for the ratio of tariffs on CFL to tariffs on IB (in the previous time period) is also included (WB, 2014).

Other variables used include an indicator for government effectiveness in policy formulation and implementation (taking the value 1 if the government is "effective", 0 otherwise). The government effectiveness indicator is created using the Government Effectiveness Index data from the World Governance Indicators Database (this index "reflects perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" (WB, 2012). Additionally, in order to derive a measure of income that is more suited to the lighting industry, the "sum of lights" variable is used, which is created using night-time satellite data, to proxy for the level of development of an economy (NOAA, 2014).

Table 1 below presents the descriptive statistics of the variables. As can be seen, the most popular policy measure is information provision, while very few countries in the sample have enforced a ban on IB.

Table 1: Summary Statistics of Independent Variables

Variable	Obs.	Mean	Std. Dev.	Min.	Max.	Missing
Information Provision(%)	1454	0.225	0.418	0	1	0
Subsidy(%)	1454	0.195	0.396	0	1	0
Ban on IB (%)	1454	0.049	0.216	0	1	0
Information IV (Distance-weighted %)	1376	1618.393	2203.139	0	13178	78
Subsidy IV (Distance-weighted %)	1348	1640.106	2124.016	0	12198	106
Ban IV (Distance-weighted %)	1400	387.857	1047.625	0	9030	54
RTA (%)	1454	0.146	0.354	0	1	0
Ratio of Lagged Tariffs	691	0.900	0.480	0	5	763
Govt. Effectiveness Index	969	0.209	0.407	0	1	485
Sum of Lights Index	1382	520766.1	1238273	592	19000000	72

Figure 1 (in the appendix) shows the policies (and their combinations) that have been adopted by countries in the data sample: it is clear that in most countries, the combination of information provision policies and subsidies is the most popular policy choice. Additionally, no country implements the ban in isolation. Information policies are relatively-well spread out amongst the countries in the sample, fewer countries have adopted price incentives to get consumers to switch from IB to CFL, and even fewer have imposed a ban on IB (this is also apparent from Figure 2, which plots the evolution of adoption rates for these three policies over time across the sample). As is clear from this graph, information policies have always been the most prevalent form of policy intervention undertaken by governments, whereas the ban has become increasingly popular since 2006-07. Figures 3 and 4 plot the share of imports and exports of CFL over time in the sample. It is clear that the share of imports of CFL has increased over time, pointing to the possibility of greater diffusion of these lamps. The increase in the share of CFL exports over time suggests that some of these countries may be becoming producers of CFL, however the exports in these countries are still not significantly large in terms of value to put into question their inclusion in the sample.

3.2 *Methodology and Results*

The objective of the empirical estimation is to explain how various policies affect the share of CFL that a country imports. The model that is estimated is as follows:

$$M_{it} = \alpha_0 + \alpha_1 D_{it} + \alpha_2 X_{it} + \mu_{it} \tag{12}$$

where M_{it} denotes the share of imports of CFL in country i at time t (over total imports of CFL and IB in country i at year t), D_{it} denote country- specific policy dummies at time t, and X_{it} denote country-specific controls in time t. μ_{it} denotes the stochastic error term. The linear-probability model is used for this estimation. There are two reasons for not converting the dependent variable to a dummy variable (and using logit or probit for estimation): firstly, many countries implemented the policies in only one year, i.e. there are "observation-specific" dummy variables as regressors (especially subsidies, and the ban on IB). Anderson (1987) has shown that neither logit nor probit can be used to estimate the coefficients on observation-specific dummy variables. Additionally, Angrist and Pischke (2008) point out that if the intention is to obtain marginal effects, the difference between non-linear methods such as logit and probit, and the linear approach adopted in this paper is not too significant.

From the onset, it is clear that there are serious endogeneity concerns in estimating model 12: it is entirely possible that policy-makers implement new policies after observing the share of imports of CFL, a risk which cannot be entirely eliminated by using lagged policy dummies, for instance. This would mean that D_{it} in (12) is endogenous. Possible existence of such reverse causality implies that OLS estimates will be inconsistent; to deal with this endogeneity concern, the model used for estimation of (12) is a linear probability model with two-stage least squares.

The baseline results of the paper only study the effects of the policies, considering them one at a time. The main reason for adopting this approach is to avoid difficulties with interpretation of coefficients with multiple endogenous variables. The first-stage robustness checks are also more tedious (Angrist and Pischke, 2008)). [7]

The instruments used for the policy dummies are constructed as weighted averages of the presence of the same policy in one of the five nearest countries to the country in question, where the weight represents the distance of the country from the neighbouring country. Data on distances are taken from the Geodist Database ((Mayer and Zignago, 2011)). There is evidence to suggest that countries in a common geographical region learn from the experiences of other countries in deciding which policies to implement (Guasch et al. (2003), Keen and Lockwood (2010), Ebeke and Ngouana (2015)). Given that energy-efficiency related policies are often implemented as regional initiatives, often in collaboration with international organisations (examples include the ECOWAS and Lighting Africa initiatives in Africa, and the UNEP En.lighten initiative in the Middle-East, Asia, Sub-Saharan Africa and Latin America), it is very likely that countries do learn from each other in implementing policies. However, it is important to keep in mind the direction of learning: it is very likely that Nepal learns from the experiences of India in implementing a policy, but the converse is not likely, given that India was one the first country in the South Asia region to implement lighting policies. To account for this possibility of unidirectional learning, the instrument is a weighted average of the presence of a policy in the five nearest countries to the given country either in period t, in period t-1, or in period t+1. This ensures that countries may learn from each other in the same time period (or with a lag), whereas if the country is a "policy leader" (the first country in the region to implement the policy), then other countries may learn from this country.

It is empirically difficult, if not impossible, to verify whether the exclusion restrictions are satisfied in this case; the Sargan-Hansen test of over-identifying restrictions can be used iff there are more instruments than included endogenous variables. However, it is difficult to identify another channel through which adoption of policies in neighbouring countries may affect the share of imports of CFL in a country, other than through its influence on a country's decision to adopt

[7] .However, certain estimations require the use of multiple endogenous variables; for instance, in order to test for the strength of the interaction between the presence of the policies government effectiveness, both the main effect (the policy dummy) and the interaction term are treated as endogenous.

Table 2: IV-2SLS Results (Second-Stage Estimation)

	(1)	(2)	(3)	(4)	(5)	(6)
Information	1.072**	3.632	–	–	–	–
	(0.487)	(9.545)				
Subsidies	–	–	1.996**	-2.418	–	–
			(0.813)	(9.828)		
Ban	–	–	–	–	1.505**	0.284
					(0.712)	(1.832)
Trade Agreement Indicator	0.103	0.054	0.276	-0.346	0.349**	0.098
	(0.194)	(0.301)	(0.226)	(1.755)	(0.141)	(0.281)
Ratio of Tariffs (in period t-1)	-0.607***	-0.341	-0.502**	-0.815	-0.797***	-0.684***
	(0.221)	(0.978)	(0.252)	(0.649)	(0.180)	(0.214)
Sum of Lights	-1.680*	-1.250	-4.710**	0.091	-2.040	-1.980**
	(0.962)	(2.950)	(2.340)	(8.230)	(1.380)	(0.780)
Government Effectiveness Indicator	0.030	0.176	-0.123	-0.062	-0.161	-0.133
	(0.145)	(0.816)	(0.167)	(0.318)	(0.131)	(0.144)
Observations	455	455	437	437	443	443
Year Fixed Effects	No	Yes	No	Yes	No	Yes

Notes: Dependent variable is share of CFL imports (in logarithm). Country fixed effects included in all estimations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

the same policies. The import share of CFL should not depend on the policies enforced in other countries, provided none of these countries are themselves large producers, and no country imports an unusually large quantity of CFL.

The baseline empirical results are provided in Table 2 below, which presents the second-stage IV-2SLS results.[8]. Table 3 presents the first-stage results corresponding to these second-stage results presented in Table 2, which are useful to evaluate the factors motivating policy-makers to opt for certain policies.

In Table 2, columns 1, 3 and 5 present the results of considering one policy at a time (information, subsidies and the ban respectively). These specifications include country fixed effects, but do not include time fixed effects. Columns 2, 4 and 6 in Table 2 present the results including year fixed effects, for the same set of policies. While theoretically it may be advisable to include time fixed effects to account for unobserved heterogeneity across different time periods, it is found to be superfluous to include them for these estimations (a joint test of the hypothesis that the coeffi-

[8] .Tables 8, 9 and 10 in the Appendix include the OLS, fixed effects and random effects estimations, considering one policy at a time. Fore reasons already mentioned, the IV- 2SLS results are the baseline results of the paper

cients on these effects are zero leads to a failure to reject the null hypothesis that they are indeed zero). Intuitively, this can be supported by the fact that the dependent variable is a ratio of imports of two similar technologies: if it is indeed the case that there is unobserved variation over time, or trends, both the numerator and the denominator are likely to pick these effects up identically in the absence of any shocks to one of the two technologies, i.e. it is unlikely that the imports of one type of lighting technology would be influenced by factors varying over time (but common for all countries in the sample) differently from the imports of the other technology. It is more important in this model to control for unobserved heterogeneity across countries, thus the emphasis on the results in columns 1,3 and 5 of Table 2.

In column 1, the coefficient on information provision is positive, and significant at the 5% level of significance, suggesting that for this sample, information policies do indeed work in encouraging imports of CFL. The coefficient on the ratio of tariffs on CFL and IB is also significant at the 1% level of significance, with the expected negative sign (higher the ratio of tariffs on these two technologies, the lower are the shares of CFL imports of countries). The sum of lights variable also has a positive coefficient, suggesting that countries that are more developed are more likely to have higher imports of CFL.

Column 3 of Table 2 includes the subsidy dummy, which has a positive coefficient and is significant at the 5% level of significance. The ratio of tariffs variable behaves as before, whereas the coefficient on the sum of night-time lights is positive, and significant at the 5% level of significance: higher the number of nighttime lights, the higher is the percentage of CFL imported by the country in a given year. The coefficient on the IB ban dummy in column 5 is positive and significant at the 5% level of significance, suggesting that, not surprisingly, the imposition of a ban on IB forces countries to import more CFL. In this specification, the trade agreement indicator is also significant at the 5% level of significance, with a positive coefficient: if the country enters a trade agreement with one of the top exporters of CFL in a given year, it is more likely to import a larger proportion of CFL in that year.

While there is no specification which includes these policy dummies all together, a comparison of the the magnitudes of the coefficients of the policy dummies from these three models suggests that subsidies are the "most effective" policy instrument for this sample, followed by the ban on IB, and lastly information provision. This suggests that in low and middle income countries, cost

Table 3: IV-2SLS Results (First-Stage Estimation)

	(1)	(2)	(3)
Information IV	0.538***	–	–
	(0.15)		
Subsidies IV	–	0.361***	–
		(0.107)	
Ban IV	–	–	0.497***
			(0.0938)
Trade Agreement Indicator	0.158*	0.0392	-0.0382
	(0.0685)	(0.0726)	(0.0441)
Ratio of Tariffs (in period t-1)	-0.193**	-0.150*	-0.00704
	(0.0592)	(0.0642)	(0.0385)
Sum of Lights	8.93	0.202**	7.99*
	(5.61)	(0.0646)	(3.95)
Government Effectiveness Indicator	-0.086	0.0323	0.0503
	(0.0893)	(0.0753)	(0.0453)
Observations	455	437	443
Cragg-Donald F-statistic	24.12	11.48	28.04

Notes: Dependent variable is the share of CFL imports (in logarithm). Country fixed effects included in all estimations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

constraints may be the most limiting barrier towards greater adoption of cleaner technologies by consumers.

Table 3 below presents the results of the first-stage estimations (the first-stage results are only reported for the results corresponding to columns 1,3 and 5 of Table 2). In column 1, the results of the first-stage model including the information provision dummy as a dependent variable are provided, while columns 2 and 3 include the results for the subsidy dummy and the ban respectively. The results in column1 provide evidence to suggest that there is learning between countries in terms of adoption of information provision policies (the coefficient on the presence of information policies in the nearest countries is positive, and significant at the 1% level of significance). While the government effectiveness index is insignificant, we also get evidence that more "developed" economies are more likely to adopt information policies (reflected by the positive coefficient on the sum of lights variable). Additionally, if the country is in a trade agreement with one of the top exporters of CFL in a given year, the country is more likely to implement information provision to encourage consumers to adopt CFL, suggesting that factors facilitating access to a technology are strongly correlated with the decision of policy-makers to inform consumers about it.

The choice of a government to provide a subsidy on CFL, (column 2, Table 3) suggests that the decisions of neighbouring countries to implement subsidies strongly influences policy-makers (the instrument has a positive coefficient, significant at the 1% level of significance), adding strength to the hypothesis that countries learn from each other in implementing policies. Additionally, more developed a country, the more likely it is to impose a subsidy on CFL (that can be ascertained by the positive coefficient on the sum of lights variable), and the higher the ratio of tariffs on the two technologies, the less likely the government is to subsidise this technology (or conversely, if tariffs of CFL with respect to those on IB decrease, the more likely the policy-maker is to subsidise them). Column 3 presents the results of the estimation of the decision of governments to ban IB: again, there is strong evidence to suggest that the decision to ban the import or sale of IB depends positively on whether neighbouring countries have also imposed this policy (the coefficient on the instrument is positive and significant at the 1% level of significance). Additionally, the ban is more likely to be implemented by countries that are more developed.

The Cragg-Donald F-statistic for identification of weak instruments is found to be 24.12 for the information IV, 11.48 for the subsidy IV and 28.04 for the IV on the ban. These satisfy the rule-of-thumb specified for weak instruments in Staiger and Stock (1997). The instruments are also larger than the critical values suggested by weak instrument-identification tests proposed in Stock and Yogo (2005), at the 15% size for two-stage least squares estimation.

In the results of Table 4 below, the policy dummies are interacted with the index of government effectiveness to test whether the efficacy with which these policies are implemented could influence the share of CFL adoption. In these specifications, the main effect is the policy dummy variable, and there is an interaction term between the policy dummy and the government effectiveness index. The interpretation of the coefficient on the main effect thus represents the marginal effect of the policy, when the policy implementation is ineffective, and the coefficient on the interaction term represents the marginal effect of the policy when it effective. The IV-2SLS methodology is not adopted for these estimations, because of the concerns with using multiple endogenous variables, which complicates interpretation of the estimates.

Column 1 of Table 4 presents the results of the estimations for the information provision policy. The effect of the information policy in the case of ineffective governments is to increase the share of CFL imports by 20.4%, whereas for effective governments, the effect of the policy is to

Table 4: Fixed Effects Estimations on the Role of Government Effectiveness in Policy Enforcement

Variables	(1) Information	(2) Subsidies	(3) Ban
Information	0.039	–	–
	(0.118)	–	–
Subsidies	–	2.481**	–
		(0.149)	
Ban	–	–	0.198**
			(0.097)
Information*Govt effectiveness	-0.565***	–	–
	(0.251)		
Subsidies*Govt effectiveness	–	-0.017	–
		(0.200)	
Ban*Govt effectiveness	–	–	0.280**
			(0.153)
Trade Agreement Indicator	0.414***	0.413***	0.406***
	(0.172)	(0.166)	(0.166)
Ratio of Tariffs (in period t-1)	-0.813***	-0.814***	-0.821***
	(0.253)	(0.245)	(0.239)
Sum of Lights	-4.870	-3.850	-5.760
	(6.010)	(6.940)	(6.640)
Government Effectiveness Indicator	0.231	-0.058	-0.121
	(0.189)	(0.151)	(0.119)
Observations	480	480	480

Notes: Dependent variable is the share of CFL imports (in logarithm). Country fixed effects included in all estimations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

reduce the share by 56.5%. The likely reason for this result is that the response to more effective governments providing information to consumers may be an increase in the domestic production capacities of these lamps. While the coefficients on both the subsidy dummy and the interaction term of this variable with the government effectiveness indicator are insignificant in column 2, in column 3 we see that the coefficient on the ban is significant and positive, even when the government is ineffective in enforcing policies (which is represented by the main effect). In the case of an effective government, the marginal effect becomes stronger (an imposition of the ban by an effective government is likely to increase the share of CFL adoption by 28%, versus 20% if the government is not effective).

In order to test for complementarities between policies, three models were estimated. In each model, two main effects (policy dummies) were included, along with their interaction term, the results of which are presented in Table 5 below. The IV-2SLS methodology is not very tractable if there are multiple endogenous instruments (and especially if the instruments are strongly corre-

Table 5: Fixed Effects Estimations on Complementarities

Dependent Variable	(1) %Share of CFL Imports	(2) %Share of CFL Imports	(3) %Share of CFL Imports
Information	0.095	0.05	–
	(0.15)	(0.16)	
Subsidies	-0.014	–	0.31
	(0.13)		(13.05)
Ban on IB	–	0.15	0.33***
		(0.11)	(0.11)
Information*Subsidies	-0.008	–	–
	(0.13)		
Information*Ban	–	0.18**	–
		(0.09)	
Subsidies*Ban	–	–	-0.25
			(0.19)
Trade Agreement Indicator	0.43***	0.44***	0.45***
	(0.16)	(0.17)	(0.16)
Ratio of tariffs (in period t-1)	-0.74***	-0.74***	-0.75***
	(0.24)	(0.24)	(0.23)
Government Effectiveness Indicator	-0.08	-0.11	-0.11
	(0.11)	(0.11)	(0.11)
Sum of Lights	2.18***	2.13***	2.13***
	(0.73)	(0.68)	(0.67)

Notes: All estimations use 480 observations. Country fixed effects included in all estimations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

lated, as shown in the correlation matrix in Table 7). Thus, a fixed effects estimation is adopted to obtain these results, despite obvious endogeneity concerns.

There is no conclusive evidence to suggest that information and subsidies are complementary, as the results in column 1 of Table 5 suggest. Both the main effects and the interaction term are insignificant. In column 2, the estimation tests for the complementarity between information provision and the ban on IB. Results suggest that in the absence of information, the ban is insignificant, whereas if there information is provided to consumers, the ban becomes effective in increasing CFL imports (the interaction is significant at the 5% level of significance). Lastly, column 3 of this table tests for possible complementarity between the ban on IB and subsidies on CFL. While the ban on IB has a strong positive (and significant) effect on CFL imports, the presence of a subsidy does nothing to augment its effectiveness (the interaction term is insignificant). These results suggest that the only possible policy combination, where one policy is more effective in the presence of another, is information and the ban on IB.

4 Policy Implications

The paper's preliminary results offer interesting policy implications. Both theoretical and empirical results indicate the importance of all three policy options such as information provision schemes, subsidies and the IB ban in encouraging CFL adoption in low and middle-income countries: in particular, price hurdles appear to be the binding constraint in low and middle-income countries (this can be confirmed by the sizes of the coefficients derived on the policy dummies in section results).

The effectiveness with which policies can be implemented (i.e. the credibility of the government providing the information, and the strength with which the ban is enforced) and the scale on which the policy can be implemented (the size of the subsidy, for example) are hypothesised to be factors which determine the choice of policy. The empirical model finds that the adoption of subsidies by governments depends positively on the level of income of the country, while the adoption of the ban on IB as an instrument depends on the effectiveness with which the government can implement policies. This was also predicted by the theoretical framework.

However, the empirical model does not find evidence to suggest that information provision is adopted by governments that are more effective. This may be attributed to the lack of a better indicator of provision of "credible" information to consumers. Given that the onus for implementing labelling schemes falls on firms, the role of the policy-maker in ensuring that accurate information is provided to consumers difficult to measure using the data that is available.

The results from the empirical model also conclude that countries learn from the experiences of their neighbours in deciding whether to implement a policy. It also finds that effectiveness in policy implementation plays a critical role in determining whether a policy has an effect on diffusion, especially in case of the ban.

The theoretical framework developed in this model suggest that when several policies are used in conjunction, it is not necessarily clear that all policies will be complementary in their effect on the share of new population switching to the new technology.The empirical results find that for this sample of countries, the ban is only effective if information provision is also adopted. This may stem from the poor enforcement of the ban in these countries. However, subsidies are not a prerequisite for the ban to be effective. This suggests that governments that are endowed with more resources for policy implementation may be better off using them to implement subsidies (which are highly effective). Countries that are more effective at policy implementation could benefit from implementing a ban on older technologies, whilst providing information to the consumers about the new technology. Conversely, governments that are not well-endowed and cannot implement policies effectively will not be able to ensure that consumers switch to cleaner technologies.

It is interesting to contrast the results of this paper with those provided by the literature on developed countries. Coad et al. (2009), for instance, provide policy implications of sequencing policies to encourage consumers to buy green cars, using Swiss survey data. They find that information provision policies (such as the energy label for cars) may be more effective when imposed at the beginning of the diffusion process, in encouraging those consumers to adopt green cars, who have an "intrinsic" green bent of mind, and who are concerned about the environmental implications of their actions. However, financial incentive schemes (such as subsidies or fines) and regulatory "sticks" may be more effective later on, to provide incentives for "extrinsically" motivated consumers who need monetary incentives to adopt a technology. Allcott and Taubinsky (2015) finds that among US consumers of clean light bulbs, information provision is the first-best policy in terms of welfare: the second-best option is a subsidy, and the ban is unlikely to lead to an improvement in consumer welfare.

I also find a positive role for trade policy in encouraging the adoption of clean technologies. For instance, trade agreements with the top exporters of certain technologies could facilitate technology transfer. Tariffs can also be lowered on clean technology which is primarily transferred through the channel of trade.

There are some caveats to the results derived in this paper. Firstly, the empirical model proxies the implementation of policies in the sample of countries by dummies, which circumvents the scale of the programs implemented, or geographical disparities. Additionally, it is also unable to account for any lags between the announcement of the policies and their implementation, which may be particularly relevant in case of the ban on incandescent bulbs, for instance because there is scant data on the dates of announcement of the incandescent ban for the countries represented in the sample. Mills and Schleich (2014) used German survey data to find that households hoarded incandescent lamps after the announcement of the policy, and before the ban was actually implemented. Such effects cannot be tested with the data used in this paper.

5 Conclusion

The objective of this paper is to evaluate the effectiveness of different types of policies in influencing the diffusion of clean technologies (such as CFL) to low and middle-income countries, which are not large producers. The main results are that for consumers who are new to a more expensive, yet more energy-efficient technology, information provision, subsidies and a ban on the incumbent technology all ensure greater adoption. However subsidies remain the most effective tool, suggesting that cost-related barriers are the most significant (at least for this particular technology, or similar ones). In addition, the decision of a policymaker to implement policies depends on the experiences of other (similar) countries, on the effectiveness with which these policies can be enforced, and the amount of resources available to the policymaker to implement these policies.

Regarding possible complementarities between policies, governments with more resources available for energy-efficiency policies may be better off using them to implement subsidies, at least in the short-run, whereas governments capable of implementing policies efficiently may benefit from banning older technologies, and simultaneously providing information to the consumers about the new technology (since they are found to be complementary policies). This analysis does not take into account welfare implications of these decisions, and is based entirely on the effectiveness of these policies.

In conclusion, this paper finds that policymakers wishing to encourage consumers in developing countries to adopt a new technology could benefit from taking into account the effectiveness of different instruments, given their resources and policy environment, and learning from the experiences of similar countries.

6 Appendix

Table 6: Countries Included in Data Sample

Albania	Costa Rica	Guatemala	Madagascar	Pakistan	Suriname
Argentina	Cote d'Ivoire	Guinea-Bissau	Malawi	Panama	Swaziland
Bangladesh	Cuba	Guyana	Malaysia	Peru	Tajikistan
Belarus	DRC	Haiti	Mali	Philippines	Togo
Belize	Dominica	Honduras	Mauritius	Romania	Tunisia
Benin	Dominican Republic	India	Mexico	Rwanda	Turkey
Bolivia	Egypt	Iran	Morocco	Saint Lucia	Uganda
Brazil	El Salvador	Jamaica	Mozambique	Senegal	Ukraine
Bulgaria	Ecuador	Jordan	Namibia	Seychelles	Venezuela
Cape Verde	Ethiopia	Kazakhstan	Nepal	South Africa	Vietnam
CAR	Gambia	Kenya	Nicaragua	Sri Lanka	Zambia
Colombia	Ghana	Lebanon	Nigeria	Sudan	Zimbabwe

Figure 1: Policies Implemented By Countries

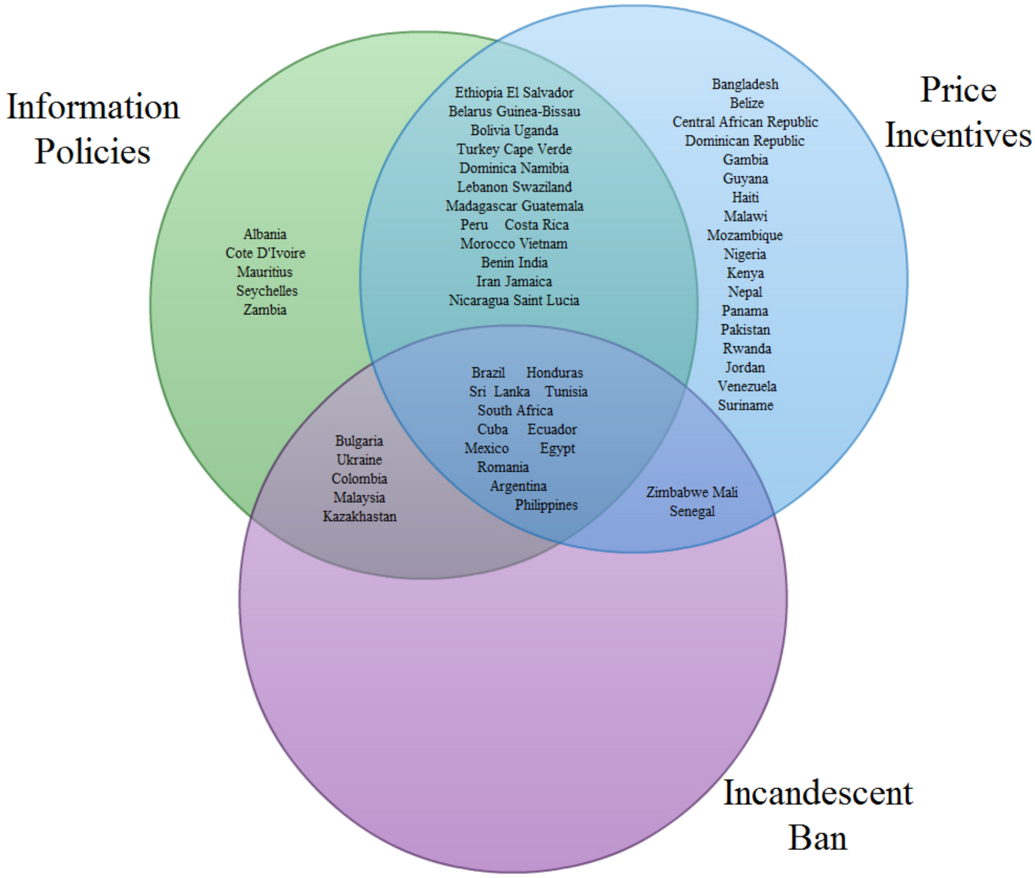

Figure 2: Policy Adoption Rates (averaged across countries)

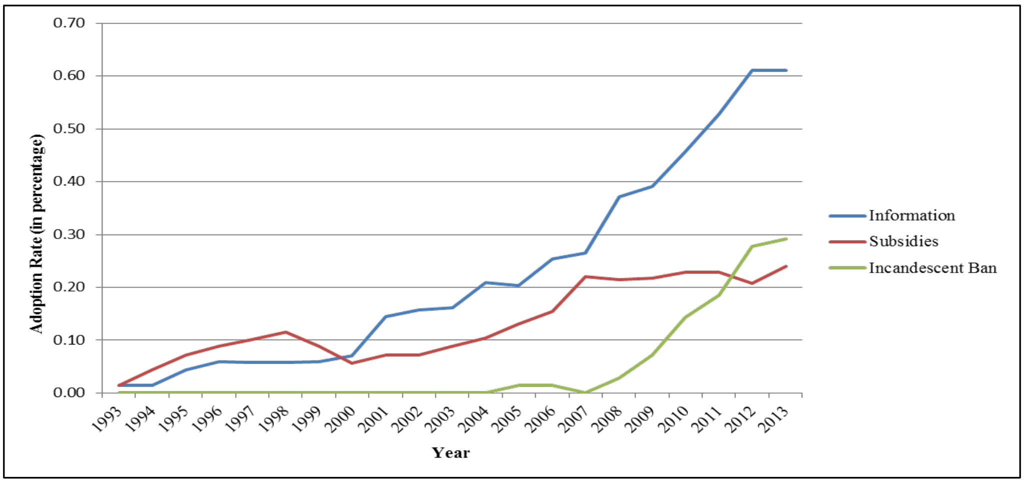

Figure 3: Evolution in Share of CFL Imports

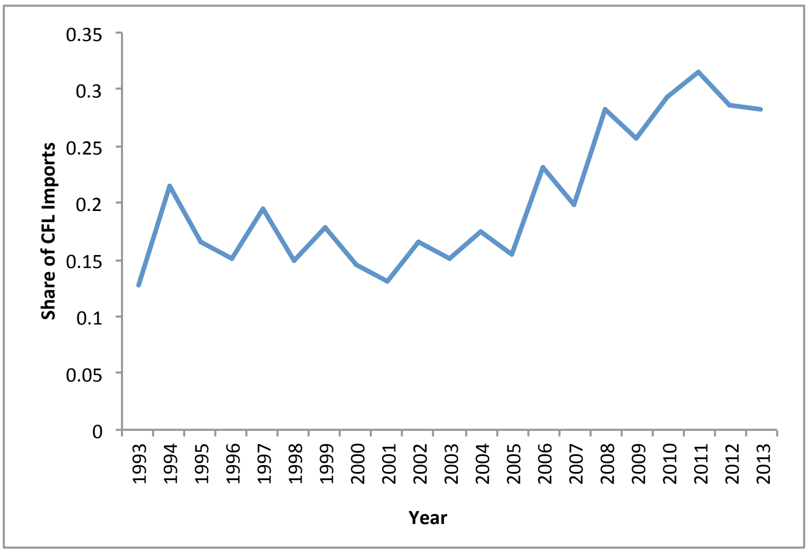

Figure 4: Evolution of Share of CFL Exports

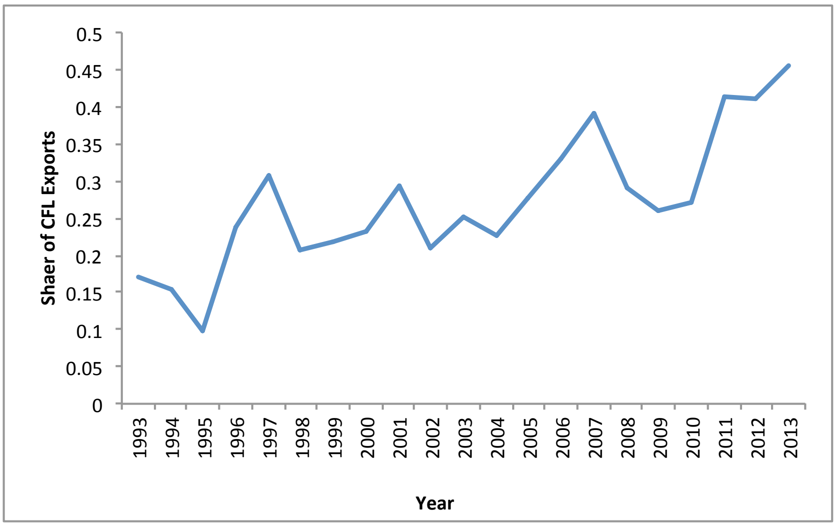

Table 7: Correlation Matrix

Pairwise Correlation Coefficients	Information Provision	Subsidy	Ban on IB	Information IV	Subsidy IV	Ban IV	Trade Agreement	Ratio of Lagged Tariffs	Govt. Effectiveness	Sum of Lights
Information Provision	1.00									
Subsidy	0.41	1.00								
Ban on IB	0.26	0.16	1.00							
Information IV	0.34	0.26	0.28	1.00						
Subsidy IV	0.35	0.27	0.27	0.73	1.00					
Ban IV	0.33	0.24	0.29	0.63	0.54	1.00				
Trade Agreement	0.30	0.12	0.12	0.32	0.18	0.29	1.00			
Ratio of Lagged Tariffs	-0.06	-0.01	-0.04	-0.08	-0.11	-0.05	-0.03	1.00		
Govt. Effectiveness	0.15	0.01	-0.01	0.07	0.10	0.01	0.24	-0.21	1.00	
Sum of Lights	0.34	0.29	0.04	0.24	0.21	0.15	0.08	0.04	0.04	1.00

Table 8: Pooled OLS, Fixed Effects and Random Effects: Information Provision

Dependent Variable	(1) Pooled OLS %Share of CFL Imports	(2) Country FE %Share of CFL Imports	(3) Country and Year FE %Share of CFL Imports	(4) RE % Share of CFL Imports
Information (including lags of periods t-1,t-2 and t-3)	0.466***	0.123	-0.189	0.156
	(0.149)	(0.134)	(0.158)	(0.137)
Trade Agreement Indicator	0.942***	0.395**	0.0693	0.425***
	(0.125)	(0.170)	(0.187)	(0.161)
Ratio of Tariffs (in period t-1)	-0.234	-0.792***	-0.676**	-0.725***
	(0.153)	(0.245)	(0.267)	(0.233)
Government Effectiveness Indicator	-0.508***	-0.0668	-0.113	-0.0901
	(0.154)	(0.107)	(0.0961)	(0.108)
Sum of Lights	2.92***	-4.46	-2.21*	2.04***
	(0.396)	(6.37)	(1.32)	(0.678)

Notes: All estimations use 480 observations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

Table 9: Pooled OLS, Fixed Effects and Random Effects: Subsidies

Dependent Variable	(1) Pooled OLS %Share of CFL Imports	(2) Country FE %Share of CFL Imports	(3) Country and Year FE %Share of CFL Imports	(4) RE % Share of CFL Imports
Subsidies (including lags of periods t-1,t-2 and t-3)	0.0788	-0.0171	-0.214*	-0.0114
	(0.145)	(0.109)	(0.108)	(0.109)
Trade Agreement Indicator	0.989***	0.419**	0.0430	0.452***
	(0.126)	(0.163)	(0.189)	(0.153)
Ratio of Tariffs (in period t-1)	-0.279*	-0.823***	-0.650**	-0.762***
	(0.156)	(0.241)	(0.266)	(0.228)
Government Effectiveness Indicator	-0.459***	-0.0642	-0.114	-0.0851
	(0.157)	(0.107)	(0.0961)	(0.107)
Sum of Lights	3.36***	-2.69	-2.34**	2.217***
	(0.40)	(5.9)	(0.116)	(0.676)

Notes: All estimations use 480 observations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

Table 10: Pooled OLS, Fixed Effects and Random Effects: Ban on IB

Dependent Variable	(1) Pooled OLS %Share of CFL Imports	(2) Country FE %Share of CFL Imports	(3) Country and Year FE %Share of CFL Imports	(4) RE % Share of CFL Imports
Ban on IB (including lags of periods t-1,t-2 and t-3)	0.885***	0.138	-0.158	0.161
	(0.285)	(0.118)	(0.194)	(0.121)
Trade Agreement Indicator	1.015***	0.415**	0.0768	0.452***
	(0.125)	(0.165)	(0.195)	(0.155)
Ratio of Tariffs (in period t-1)	-0.270*	-0.818***	-0.659**	-0.753***
	(0.152)	(0.238)	(0.268)	(0.225)
Government Effectiveness Indicator	-0.452***	-0.0751	-0.107	-0.0973
	(0.153)	(0.103)	(0.0987)	(0.106)
Sum of Lights	3.45***	-3.43	-2.17*	2.25***
	(0.37)	(0.61)	(1.3)	(0.66)

Notes: All estimations use 480 observations. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

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