Using Regression Discontinuity Models to Understand Market Transformation

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ABSTRACT

During the past ten years, China has become one of the largest consumers as well as the largest exporter of lighting products. The efficiency of lighting products made in China thus has significant implications for lighting efficiency, electricity consumption, greenhouse gas emissions and sustainable development. The China Green Lights program invested some 300 million yuan to transform the domestic lighting market by increasing the supply of and demand for efficient lighting products. This study uses regression discontinuity models combined with engineering algorithms to evaluate the impact of the China Green Lights program. The study has four main conclusions. First, domestic market penetration of energy-efficient compact fluorescent lamps and T5 and T8 fluorescent tubes increased substantially during the China Green Lights program. Second, based on econometric estimates, China Green Lights led to increased sales of 56 million compact fluorescent lamps and 50 million T5 and T8 tubes per year. Third, based on engineering algorithms, the increased sales of efficient lighting led to energy savings of 9,928 GWh per year and reduced carbon dioxide emissions of 6,178 kilotonnes per year. Fourth, regression discontinuity modeling is a promising evaluation approach for market transformation programs where the conventional pre-post difference with a comparison group evaluation model is often not applicable.

Introduction

Over two decades, the Chinese economy increased about six-fold as GDP increased from about 1.366 trillion yuan in 1980 to about 8.043 trillion yuan in 1999, in constant 1995 yuan. During this period, energy consumption more than doubled from about 17.7 EJ in 1980 to about 39.1 EJ in 1999. Although the real GDP to energy ratio has thus fallen substantially over the past twenty years, China still uses energy inefficiently compared to the industrialized countries. Inefficient use of energy is a significant constraint on Chinese economic and social development, and the need to improve energy efficiency has motivated the Government of China to embark on an aggressive program of demand side management activities [Sinton and Fridley (2000)].

During the past ten years, China has become the largest producer as well as one of the largest consumers of lighting products. The efficiency of lighting products in China thus has significant implications for world wide lighting efficiency, electricity consumption, greenhouse gas emissions and sustainable development. Lighting currently accounts for more than 13% of the electricity used in China, and over the period 1900 to 2000, the demand for electricity for lighting use grew at a rate of fifteen percent per year. With rising industrial activity and improving standards of living, the growth in lighting demand for electricity is expected to continue to grow [United Nations Development Program (2000)].

Several papers have explored various aspects of lighting efficiency in China. Sinton, Levine, and Qingyi (1998) examined the current state of energy efficiency in China. They concluded that there were a number of cost-effective opportunities for improving Chinese lighting efficiency. Min, Mills, and Zhang (1997) comprehensively examined technical aspects of Chinese lighting products. They noted that key issues facing the lighting industry included low lighting efficiency in terms of lumens per watt for Chinese lighting products, relatively short lamp life, and low penetration levels of efficient products in China. Zhang (2001) examined lighting standards and lighting intensity in various countries. He found that lighting unit power densities in China were generally in line with those of the United States and Japan, but allowing for lower lighting efficiency this implies that some types of building space may be significantly under lit in China. Yansheng (2001) reviewed the current status and prospects for the Chinese lighting industry. He noted that the industry has shown strong domestic growth and excellent export performance, but that export growth, in particular, requires high quality lighting products for export. Liu, Lu, Hinge and Jeffcott (2002) reported on potential energy savings and barriers in the lighting field in China. They reported that there is potential to reduce China's electricity consumption for lighting by 40% thru use of more efficient lighting technologies, but that substantial barriers remain.

The most significant initiative to date in the lighting field in China has been the China Green Lights program. The initial program invested some 300 million yuan or about US$36 million to improve the demand-side and the supply-side of the Chinese lighting market. It has been followed by a second China Green Lights program, which is addressing remaining supply-side and demand-side barriers. The second program was initially budgeted at some 200 million yuan or about US$26 million and is currently being implemented. The purpose of this paper is to estimate the impacts of the first China Green Lights program.

Program Description

Lighting is probably the largest and fastest growing use for electricity in China; lighting end-uses consume about 13% of overall electricity production. From 1988 to 1998, estimated consumption for lighting increased from 44TWh per year to 152TWh per year. Key factors leading to increased use of electricity for lighting include the following: increased numbers of commercial buildings built to international standards; enhanced use of residential electric lighting as living standards increase; and greater domestic and international investment in new manufacturing facilities for domestic and exported production [Liu, Lu, Hinge and Jeffcott (2002)].

The State Economic and Trade Commission launched China Green Lights in October 1996 with the support of the United Nations Development Program. The purpose of the China Green Lights program was to transform the inefficient lighting market in China by removing social and economic barriers to the use of efficient lighting products. More specifically the anticipated program outcomes were increased purchases and market share of CFL lamps and increased purchases and market share of T5 and T8 fluorescent tubes, while the anticipated program impacts were reduced lighting-related energy consumption and reduced carbon dioxide emissions.

The rationale for the China Green Lights program was to identify and implement activities to systematically overcome critical market barriers. The activities undertaken under the China Green Lights program to address these barriers can be grouped into four main categories as follows: (1) increasing consumer awareness; (2) developing market-based demand-side mechanisms; (3) developing quality control and performance standards; (4) developing market-based supply-side financing mechanisms.

Activities to increase consumer awareness of the nature and benefits of energy efficient lighting products included: three international symposia and six domestic workshops; two poster campaigns, two brochures, numerous articles as well as special issues in major newspapers and trade journals; two television programs aired on the largest domestic television network; publication of a catalogue of efficient lighting products; establishment of the China Green Lights Beijing Exhibition Centre; demonstration projects in a variety of areas; and cooperative advertising with manufacturers.

Activities to develop market-based demand-side mechanisms included: consumer rebate program that provided a 5 to 10 yuan rebate on the typical 25 yuan price of a CFL; additional subsidies for bulk purchases; reduced connection charge and reduced electrical tariff for owners of new buildings who agreed to use energy efficient lighting; development of a pilot program for facility consumption targets for businesses with credits for consuming less and penalties for consuming more than the targets; implementation of a time of use rate for large consumers; development of ESCOs; lease to own arrangements for CFLs in large facilities with repayment at 2 yuan per month for 12 months; and quality assurance desks.

Activities to develop quality control and performance standards included: surveys of manufacturing production capabilities by plant; provision of technical advice to manufacturers on how to improve facilities and their products; technical research for standards development; upgrading of capability in government product testing facilities; development of voluntary standards for single pin CFLs and self-ballasted CFLs; lighting design guidelines for hotels and retail establishments; and workshops on performance standards, certification and quality control.

Activities to provide supply-side financial support for green lights manufacturing included: research and surveys on financing needs; development of a policy on financing requirements for expansion and upgrading of production facilities; provision of grants and soft loans for upgrading and expansion of production facilities; and workshops and seminars on current product standards as well as anticipated future standards for additional products.

Evaluation Approach

In recent years considerable attention has been placed on market transformation for energy using technologies and a number of papers have used regression models to evaluate energy market transformation programs. A full review of these papers is beyond the scope of this study, but it is worthwhile to summarize the relatively few published studies that have used econometric methods similar to that used in the present study. Duke and Kammen (1999) conducted an extensive study of electronic ballasts. Their methodology used experience curves and demand feedback effects to estimate the response of market demand to program induced cost reductions. They found that accounting for feedback between the demand response and production response significantly improves the consumer cost benefit ratio. Horowitz (2001), using the same data set, modeled electronic ballast price and quantity responses for the pre-Green Lights (control) and post-Green Lights (treatment) periods. He concluded that it is cost-effective to transform a national market through long-term, coordinated, coast-to-coast efforts rather than local market initiatives. Horowitz and Haeri (1990) explored how participation in the Model Conservation Standards program affected the sales price of new and recent resale residential housing. They found that the cost of energy efficiency was fully capitalized in housing price and that purchasing an energy efficient house was cost effective. Jaffe and Stavins (1995) examined the determinants of ceiling, wall and floor insulation levels. They concluded that insulation levels in new residential housing appropriately reflect energy prices. Newell, Jaffe and Stavins (1999) looked at room air conditioners, central air conditioners and water heaters. They found that higher energy prices are a partial determinant of adoption of efficient appliances.

The basic approach of this study is as follows. First, information from the China Association of Light Industry is used to build a database of production, exports and domestic consumption for various lighting products. Second, regression discontinuity models (sometimes referred to as interrupted time-series models) are applied to this data to understand the apparent net impact of the China Green Lights program on quantities manufactured and quantities purchased domestically for CFL, incandescent (GLS), T5 and T8, and T9 to T12 lamps. In the simple regression framework employed, it is assumed that all non-program factors are captured by a time-trend term so that the coefficient on a dummy variable for the program period measures program impact. Third, using local engineering data, algorithms are used to estimate the energy savings for each efficient technology as well as the impact of energy savings on carbon dioxide emissions. Evaluation issues, data sources used and methodologies are summarized in Table 1.

Table 1: Issues, Data Sources and Methodologies

Issue	Data Source	Methodology
Measure market penetration of efficient lighting	Chinese Lighting Industry Association data	Market share analysis
Estimate impact on domestic production and consumption of products	Chinese Lighting Industry Association data	Regression modeling
Estimate impact on domestic energy savings and CO_2 emissions	Interviews Literature review Site visits	Algorithms

The most consistent and reliable source of information on production and exports of lighting products in China is that collected by the China Light Industry Association. Discussions with officials of the China Green Lights program and the State Economic and Trade Commission indicated that this information was reliable enough to support a regression-based analysis. Production information is based on surveys of all large and medium and many small manufacturers of lighting products. Coverage is relatively comprehensive since the production of small producers is less than ten percent of the market. Export and import information is collected by the State Economic and Trade Commission and then reconciled with production information. Domestic consumption was estimated as production minus net exports for each product category.

The time series of thirteen years of information (1988 to 2000) is relatively short for econometric modeling. For this reason, a number of parsimonious preliminary specifications were estimated. Independent variables used in the preliminary specifications included nominal gross national product, real gross national product, an index of physical output and a simple time trend. The simple time trend performed the best. Specifications involving both the levels of the dependent variables and logs of the dependent variables were also used in preliminary specifications. The equations in the levels of variables performed best.

Market Penetration

In examining market penetration, it would be ideal in some respects to understand the change in the share of lighting points, by segment, populated by different types of lamps, but this information is not available. Instead, given data limitations, we focus on the extent of market transformation in terms of sales in just two markets, efficient bulbs and efficient fluorescent tubes. It would also be useful to examine the shift from mercury vapour to high pressure sodium, in particular, for street lighting and large area lighting purposes, but the detailed information on production and sales needed to undertake this analysis was not available.

In order to estimate market penetration for efficient bulbs, we need to first define the market being considered. For efficient bulbs, we define the market as the sum of sales of incandescent plus compact fluorescent lamps. As Table 2 indicates, domestic sales of incandescent lamps increased substantially from 1990 to 1995 but then fell substantially from 1995 to 2000, coincident with the introduction of China Green Lights. Domestic sales of compact fluorescent lamps increased steadily from 1990 to 1995 to 2000. The net result was an increase in the CFL sales market share from 0.6% in 1990 to 0.9% in 1995 and to 14.5% in 2000. Over the period 1990 to 2000, there was a substantial increase in the market penetration of CFLs.

Table 2: Domestic Sales and Market Penetration for Efficient Bulbs (millions)

	1990	1995	2000
General incandescent	1690	2750	1300
CFLs	10	25	220
General service plus CFLs	1700	2775	1520
CFL share	0.6%	0.9%	14.5%

Source: China Association of Light Industry.

In order to estimate market penetration for efficient tubes, we also need to first define the market being considered. For efficient tubes, we define the market as the sum of sales of efficient T5 and T8 tubes plus less efficient T9 to T12 tubes. As shown in Table 3, domestic sales of T9 to T12 tubes increased substantially from 1990 to 1995 but then fell marginally from 1995 to 2000, coincident with the introduction of China Green Lights. Domestic sales of T5 and T8 tubes increased steadily from 1990 to 1995 to 2000. The net result was an increase in the sales market share of efficient tubes from 2.4% in 1990 to 5.8% in 1995 and to 27.3% in 2000. Over the period 1990 to 2000, there was a substantial increase in the market penetration of efficient fluorescent tubes.

Table 3: Apparent Domestic Sales and Market Penetration for Efficient Tubes (millions)

	1990	1995	2000
Linear fluorescent T9-T12	200	325	320
Linear fluorescent T5 and T8	5	20	120
All linear fluorescents	205	345	440
T5 and T8 share	2.4%	5.8%	27.3%

Source: China Association of Light Industry.

Impact on Production and Sales

Table 4 provides the regression results for lamp production using the regression discontinuity model for the thirteen years from 1988 to 2000. The dependent variable in each case is the production of the relevant lamp in millions of units. The coefficient on the time trend accounts for non-program variables affecting lamp production, while the coefficient on the Green Lights dummy variable estimates the apparent impact of the program on lamp production for the four years of the post-program period, 1997-2000. Since only thirteen years of data are available, relatively modest alternative specifications were estimated, using a limited number of independent variables as noted above.

Given the relatively short length of the time series, the statistical results are acceptable: coefficients on the time trend are statistically significant and have the correct signs; coefficients on Green Lights are positive for efficient products and negative for standard products, as expected, and statistically significant in three out of four cases (for all but T9-T12 tubes). R-squared values are acceptable, indicating, a good overall fit for a linear model. The one statistical problem with the regressions is the relatively low values of the Durbin-Watson statistics that suggest the possibility of autocorrelation. The usual approach to autocorrelation, fitting a first-order autoregressive scheme to the data, actually resulted in worse results in terms of the Durbin-Watson statistics, so we prefer to use the ordinary least squares regression results reported here. The interpretation of the key China Green Lights coefficient is as follows: for each of the four years 1997-2000, the program resulted in an apparent increase of CFLs production of 113 million units per year, a decrease of GLS production of 799 million units per year, an increase in T5 and T8 production of 54 million units per year, and a decrease in T9-T12 production of 27 million units per year.

Table 4: Impact of China Green Lights on Lamp Production (millions)

	CFL	GLS	T5 and T8	T9-T12
Constant	-58 (-1.23)	1073 (6.65)	-14 (-1.10)	146 (5.37)
Year	19 (2.30)	226 (7.94)	6 (2.50)	21 (4.42)
Green Lights	113 (1.68)	-799 (-3.47)	54 (2.96)	-27 (-0.70)
Adjusted R^2	0.76	0.86	0.86	0.77
DW	0.90	1.30	1.19	1.58

Note: T-statistics for coefficients are shown in parentheses. DW is the Durbin-Watson statistic.

Table 5 provides the regression results for lamp consumption using the regression discontinuity model for the thirteen years from 1988 to 2000. The dependent variable in each case is the consumption of the relevant lamp in millions of units. The coefficient on the time trend accounts for non-program variables affecting lamp consumption, while the coefficient on the Green Lights dummy variable estimates the impact of the program on lamp consumption for the four years of the post-program period, 1997-2000. Again, relatively modest alternative specifications were estimated, without improving results.

The statistical results are once more acceptable: coefficients on the time trend are statistically significant and have the correct signs; coefficients on Green Lights are positive for efficient products and negative for standard products, as expected, and statistically significant in three out of four cases (for all but T9-T12 tubes). R-squared values are acceptable, although low for the GLS equation, but the Durbin-Watson statistics are quite low as before. Once again, fitting a first-order autoregressive scheme to the consumption data, actually resulted in worse results in terms of the Durbin-Watson statistics. The interpretation of the key China Green Lights coefficient is as follows: for each of the four years 1997-2000, the program resulted in an apparent increase of CFLs consumption of 56 million units per year, a decrease of GLS consumption of 1167 million units per year, an increase in T5 and T8 consumption of 50 million units per year, and a decrease in T9-T12 consumption of 44 million units per year.

Table 5: Impact of China Green Lights on Domestic Lamp Consumption (millions)

	CFL	GLS	T5 and T8	T10-T12
Constant	-26 (-1.08)	1253 (3.29)	-11 (-1.18)	150 (4.60)
Year	9 (2.06)	171 (2.55)	5 (3.14)	20 (3.54)
Green Lights	56 (1.69)	-1167 (-2.15)	50 (3.92)	-44 (-0.95)
Adjusted R^2	0.73	0.28	0.91	0.63
DW	0.87	0.80	1.61	1.46

Note: T-statistics are shown in parentheses. DW is the Durbin-Watson statistic.

Impact on Energy savings and Carbon Dioxide Emissions

Engineering algorithms were used to estimate annual domestic energy savings and annual greenhouse gas emission reductions, assuming that the shift in the market was confined to the four years 1997-2000. Lamp wattages and hours of use were based mainly on Min, Mills and Zhang (1997), but also confirmed as reasonable through interviews with Chinese lighting experts and brief visits to some 40 establishments. For fluorescent tubes it was assumed that there was an equal share of two-foot and four-foot tubes, based on site visit observations. Carbon emissions per kWh came from the China Green Lights program, grossed up to equivalent carbon dioxide emissions using the atomic weights of carbon and oxygen. As shown in Table 6, annual energy savings for incremental sales of CFLs was 5,496 GWh and for incremental sales of T5 and T8s was 682 GWh for total energy savings of 6178 GWh. Annual carbon dioxide reductions were 5,496 kilotonnes for CFLs and 682 kilotonnes for T5 and T8s for a total of 6, 178 kilotonnes.

Table 6: Annual Incremental Domestic Energy Savings and Carbon Dioxide

Comparison	Base lamp (W)	Efficient lamp (W)	Unit savings (W)	Hours (per year)	Number of units (million)	Total savings (GWh)	CO_2 reduction (kilotonnes)
CFL vs. GLS	40	13	27	1460	224	8832	5495.6
T8 vs. T12	30	27	3	1825	200	1096	682.0
Total					424	9928	6177.6

Source: Min, Mills and Zhang (1997), site visits, author's regressions.

Conclusions

Conclusion 1: Market penetration. Domestic market penetration of energy-efficient compact fluorescent lamps and T5 and T8 fluorescent tubes increased substantially during the China Green Lights program. For lamps, sales market share of efficient compact fluorescent lamps increased from 0.6% in 1990 to 0.9% in 1995 and to 14.5% in 2000. For tubes, sales market share of efficient T5 and T8 tubes increased from 2.4% in 1990 to 5.8% in 1995 and to 27.3% in 2000. These are substantial increases in market penetration.

Conclusion 2: Production and Consumption. For each of the four years 1997-2000, the program apparently resulted in an increase of CFLs production of 113 million units per year, a decrease of GLS production of 799 million units per year, an increase in T5 and T8 production of 54 million units per year, and a decrease in T9-T12 production of 27 million units per year. For each of the four years 1997-2000, the program apparently resulted in an increase of CFLs consumption of 56 million units per year, a decrease of GLS consumption of 1167 million units per year, an increase in T5 and T8 consumption of 50 million units per year, and a decrease in T9-T12 consumption of 44 million units per year.

Conclusion 3: Energy Savings and Carbon Dioxide Emissions. Simple engineering algorithms were used to estimate annual domestic energy savings and annual greenhouse gas emission reductions, assuming that the shift in the market was confined to the four years 1997-2000. Based on the algorithms, annual energy savings for incremental sales of CFLs was 5,496 GWh and for incremental sales of T5 and T8s was 682 GWh for total energy savings of 6,178 GWh. Annual carbon dioxide reductions were 5,496 kilotonnes for CFLs and 682 kilotonnes for T5 and T8s for a total of 6,178 kilotonnes.

Conclusion 4: Appropriateness of Regression Discontinuity Approach. Regression discontinuity modeling is a promising evaluation approach for market transformation programs where the conventional pre-post difference with a comparison group evaluation model is often not applicable. But like other regression- based analysis, the regression discontinuity approach is vulnerable to omitted variable bias, so that care must be used in attributing impacts to a program on the basis of regression results.

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