# The Impact of Smart City Policy on Green Innovation: Evidence from an Empirical Analysis in India

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**KIM, Inae**

**THESIS**

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Committee in charge:

Professor Yoon, Chungeun, Supervisor ____________

Professor Joo,Yu Min ____________

Professor Lim, Wonhyuk ____________

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**Abstract**

A smart city is designed to use technologies to improve the quality of life and help achieve sustainability and climate goals. There is a growing literature that analyses the impact of smart cities on urban innovation or $CO_2$ reduction in developed countries, but few studies explore the relationship between smart cities and innovation in developing countries. This paper examines the effect of smart city policy on green innovation in the context of a developing country. Specifically, I investigate the effect of building new smart cities on environmental patent applications in India using panel data on 26 Indian state-level patents over the period 2001-2020. I find that a 10% increase in the proportion of smart cities was associated with a 17% increase in environmental patent applications. This effect was stronger for smaller states that experienced a 32% increase. Furthermore, I show that there were significant effects on patenting activities in environmental sectors: “air pollution abatement technology”, “waste management technology”, and “climate change mitigation technologies associated with energy and transportation”. The results suggest that smart cities in developing countries can play a critical role in encouraging green innovation.

*Keywords:* smart city policy, green innovation, policy

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## I. Introduction

In recent years, central issues in climate change are dealing with urban environmental issues where 56.15% of the world's population lives (The World Bank, 2020) and reaching the goals of the Paris Agreement. Urban environmental issues are expected to be much more severe as the urban population grows. Furthermore, it is one of the biggest issues how to meet their Paris Agreement commitments. India, the second largest populated country in the world, is not an exception. With drastic urbanization, the share of the urban population rapidly grew to 31.16% in 2011, which compares with 17.96% in 1961, projecting it to be half of the population of India by the year 2040 (Census of India, 2011).

India has also many environmental issues such as air pollution, waste, and water-related problems (Chopra, 2016). In addition, by 2030, under the Paris Agreement, India, the third largest carbon emitter in the world, has committed to cut greenhouse gas emissions by 33-35% of its GDP from 2005 levels (Khadka, 2021). This is a critical matter of concern not only because environmental issues are directly related to health and livelihood impacts in urban areas where the majority of the citizens reside, but also because it seems that an entirely new way of life and industry structure are needed for India to meet its Paris agreement commitments, as its economy hugely relies on the mining industry.

In particular, the GDP of the total industry is contributed by the mining industry by approximately 10% to 11% (Agencies, 2017). Coal-based power accounts for about 70% of all power produced in India (Deshmane, 2021). India might face challenges, given that it has promised to produce half of the power from renewable energy by 2030, and to cut its emissions towards net zero by 2070, besides the Paris Agreement.

Meanwhile, smart cities are often envisioned to be a solution to both urban challenges and reaching the goals of the Paris Agreement for climate change mitigation. Many countries have been developing smart cities with big ambitions. Developing countries, which previously had difficulty in financial support (Yigitcanlar and Lee, 2014), have begun to drive smart city initiatives actively with more resources in the past decade (Gupta et al., 2021).

In particular, the Indian government announced a grand initiative in 2015, called Smart Cities Mission (SCM). Under SCM, 100 cities were selected as smart cities to be developed in five rounds: round1, fast track, round2 in the year of 2016, round3 in 2017, and round4 in 2018 by the Ministry of Urban Development. Figure 1 shows that 60 cities prevailed against other cities in the countrywide Smart Cities challenge in 2016 – 20 cities in round1, 13 cities in fast track, 27 cities in round2 - and 30 more cities were announced to be upgraded as part of the SCM in 2017. As of 2020, 100 cities in total had been designated as smart cities over five rounds of selection since SCM launched in 2015. Figure 2 shows that these cities are spread out across the country; 35 states include at least one smart city among 37 states and Union Territories. As one of the top 10 largest states in India, Uttar Pradesh, Tamil Nadu, and Maharashtra stand out with the highest number of smart cities. Covering 5,196 projects and 21% of India's urban population, SCM aims to "promote cities that provide core infrastructure, clean and sustainable environment and give a decent quality of life to their citizens through the application of 'smart solutions'" (Ministry of Urban Development, 2015). The Indian government gave financial support US$140 million to 100 cities each between 2016 and 2020 for SCM projects (Praharaj & Han, 2019), and longs for these cities acting as lighthouses to other aspiring cities.

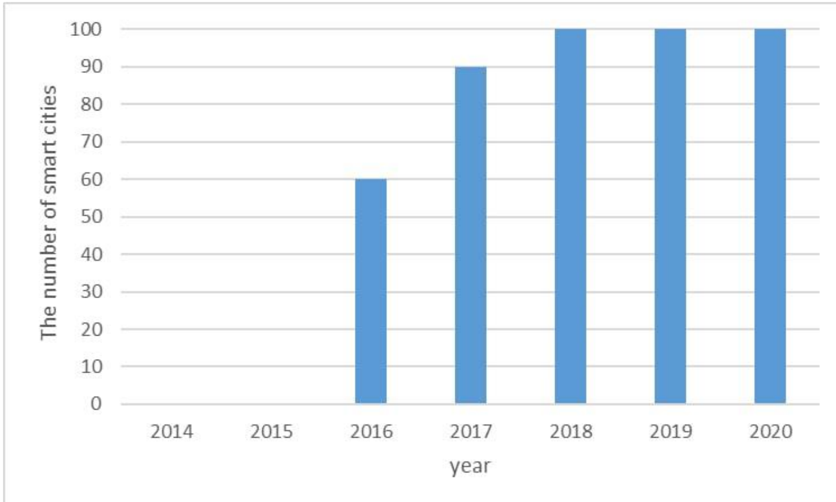


**Figure 1. Number of cities selected by the Smart Cities Mission**

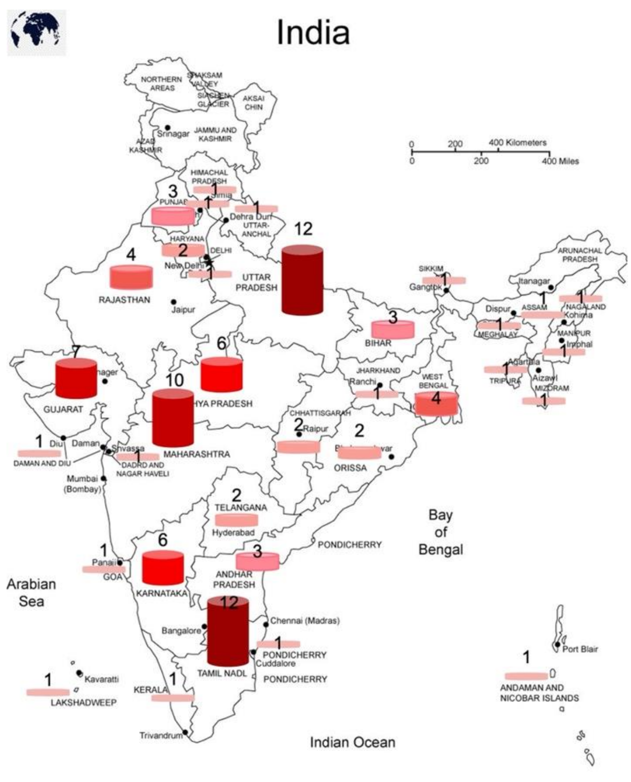


**Figure 2. Number of cities selected by the Smart Cities Mission from states/Union Territories**

*Note: The author made the figure based on the smart cities list provided by the Ministry of Housing and Urban Affairs, India. (http://164.100.161.224/content/city_challenge.php)*

The extant literature supports many governments' wishes to resolve their urban challenge by harnessing emerging information and communication technology (ICT) with urban innovation. It has been claimed that smart city policy is likely to lead to innovation (Caragliu & Bo, 2019; Xu et al., 2020). Caragliu and Bo (2019) have argued that smart cities are likely to patent more arduously than normal cities. Xu et al. (2020) also showed that innovation is positively affected by smart city policy. However, relatively little research has examined the effect of smart city policy in the developing country context. Moreover, there remains a question whether smart city policy can be a trigger for its green innovation dealing with urban environmental problems in developing countries, especially India. First, while much literature emphasizes the role of smart city in leading sustainable outcomes (Shruti et al., 2020; Ahvenniemi et al., 2017; Yigitcanlar & Kamruzzaman, 2018), India's SCM has been criticized for the mission's failure to prioritize environments over other sectors (Gulati, 2021). In contrast, most of the 114 EU Smart City projects after 2010 are related to the environment and energy (Caragliu & Bo, 2019). Secondly, India has a reputation of being a minnow in terms of patents and R&D, as OECD shows that only 0.7% of its GDP was spent on R&D from 2016 to 2017, while 3.2%, 2.8%, and 2.1% were spent by Japan, the US and China, respectively (Seetharaman, 2019). It remained at 0.7% in 2017-2018, as well. Furthermore, India has remained in the 40$^{th}$ position out of 53 countries in the Global Intellectual Property Index. According to WIPO Statistics Database (2020), the Indian intellectual property (IP) office received more than three times lower volumes of applications (53,627) than the European Patent Office (EPO, 181,479), while China (1,400,661), U.S. (621,453), Japan (307,969), and the Republic of Korea (218,975) received plenty of applications in 2019. Moreover, non-resident filing accounts for 63.7% of the application. Low patenting activity can be attributed to low R&D investments, Low intellectual property (IP) literacy, poor infrastructure, and limited resources. Given this situation, it is a question whether the ambitious smart city policy of India boosts innovation or green innovation.

In summary, previous research has paid attention to the impact of smart cities on innovation in the developed country context, rather than the developing country context. Although researchers have shown that smart city policy positively affects urban innovation, few studied the environmental innovation effects. My research builds on existing work by exploring smart city policy's incorporate environmental effects on innovation in the developing country, especially India.

The purpose of this paper is to investigate the effect of smart city policy on green innovation in the context of India and suggest policy implications and future directions of smart city policy to promote innovation for the environment. The following research questions will guide this study:

1) To what extent does the smart city policy of India promote innovation?

2) To what degree does the smart city policy of India promote urban green innovation?

3) Does green innovation happen more in cities that have greater intensity of smart city policy regarding environmental issues than other cities?

To answer these questions, a data set on 26 Indian states and green innovation outputs over the period 2001-2020 from OECD REGPAT DATABASE (July 2021 edition) is used. The latter are estimated using environment-related patent applications to the Patent Cooperation Treaty from 2001 to 2020, by matching with the Cooperative Patent Classification (CPC) codes according to the ENV-TECH classification (OECD, 2016). Employing difference-in-differences methods, the outcomes for states that were heavily affected by the smart city policy are compared with the outcomes for states that were not considerably affected.

The results show that smart city policy encouraged environmental patent activity. I find that a 10% increase in the proportion of smart cities is associated with a 17% increase in environmental patent application. This effect is stronger for smaller states with a 32% increase, compared to bigger states. In huge states, a variety of factors can be far more influential than the smart city policy. Furthermore, I show significant effects on patenting activity concerning air pollution abatement technology, waste management technology, and energy and transportation technologies for climate change mitigation. Indeed, Indian Smart Cities Mission is involved in many environmental projects such as Solar panels and street light projects, “Construction of charging station for operating 50 electrical buses” project, and “Eco-restoration of Assi River by wastewater treatment” project. The results imply that it is crucial to develop smart city policy that embraces sustainable influence, rather than focuses only on the technology itself, as developing countries tend to build smart cities by building massive infrastructure which not only requires a large amount of the cost but also has lasting impacts on the environment and citizens.

The remainder of this paper is organized as follows. Section 2 discusses existing literature about the role of smart city policy on innovation and the environment. Section 3 and 4 describe the data and the empirical methodology used in the paper. I present the main results in Section 5. Section 6 concludes.

# II. Literature Review

In addressing the issue of climate change and urban environmental problems, governments have considered several approaches for harnessing emerging technology: promoting the development of energy efficient technology, utilizing Internet of Things (IoT) for water management, and adopting Artificial Intelligence (AI) technology for waste management. Building on this, many countries have announced their ambitious and comprehensive smart city policies to resolve urban problems creatively. Before proceeding further, it is necessary to clearly define the key terminology referred to in this paper: What is a smart city? The definition of the concept has been vague (Vanolo, 2014; Carvalho, 2015) without a commonly agreed one (Yigitcanlar et al., 2018). Most simply, it is defined as “the convergence of technology and the city” (Yigitcanlar et al., 2018, p. 145). According to Glasmeier and Christopherson (2015), however, the smart city concept is often limited to “a few approaches that use publicly available data to solve discrete problems, such as waste management and traffic control” (p. 6). In this paper, smart cities in India refer to cities designated as smart cities by India's Smart Cities Mission (SCM).

The literature on the effects of smart city policies is divided into two – impacts on innovation and impacts on sustainability. This section provides summaries of those two main strands of literature. I begin with some highlights of the literature on smart city and innovation are reviewed in Section 2.1.

### *2.1. Smart city and innovation*

Does a smart city policy make cities more innovative? Previous work on the effects of smart city policies on innovation or patent activity as a proxy supports a positive relationship between them (Caragliu & del Bo, 2019; Xu et al., 2020). Caragliu and Bo (2019) have argued that smart cities are likely to patent more arduously than normal cities. Xu et al. (2020) also showed that innovation is positively affected by smart city policy in China. However, relatively little research has examined the effect of smart city policy on environmental-related innovation. Does smart city policy promote all types of patent activity including technology for mitigating climate change or for reducing the energy intensity to the similar extent? Does smart city policy lead to an increase in other types of patent application? How has environment-related patenting innovation been changed? This paper will explore how the number of green patent application has been changed by smart city policies.

### *2.2. Smart city and sustainable outcomes*

A growing body of literature emphasizes the importance of the role of smart city in leading sustainable outcomes (Shruti et al., 2021; see also Ahvenniemi et al., 2017; Yigitcanlar & Kamruzzaman, 2018). According to Shruti et al. (2021), sustainability is perceived as a fundamental element of smart city design. Likewise, Ahvenniemi et al. (2017) highlight “the role of technologies in smart cities should be in enabling sustainable development of cities, not in the new technology as an end in itself. Ultimately, a city that is not sustainable is not really smart” (p. 242). Yigitcanlar and Kamruzzaman (2018) support this opinion through their study in the case of UK cities which failed to contribute to concrete sustainable outcomes and called for reforming those cities. At this point, I believe that policymakers and researchers need to identify whether smart cities are indeed productive to sustainability, in reality.

A few studies of the effect of smart city policy on sustainability have shown a positive correlation between smart city policy intensity and sustainable outcomes (e.g., Chen et al., 2017; Zhang et al., 2018 for a discussion of China context; cf. Yigitcanlar & Kamruzzaman, 2018 for a review of different results with 15 UK cities). For a comprehensive discussion, Xin et al. (2021) summarized the extant literature, mostly conducted in developed country context and China (for a useful analysis on the relationship between carbon dioxide emissions and innovation in a European context see Mongo et al., 2021; Töbelmann & Wendler, 2020; Fernández et al., 2018; for China context see Shahbaz et al., 2020). It is not clear, however, whether this literature applies to India and other developing countries, since developing countries have been focusing more on economic and social sustainability rather than environmental sustainability. In other words, the environmental concerns are often eclipsed by two other dimensions of sustainable development in many smart city policies (Shruti et al., 2021) and implementation. Particularly, India's Smart City Mission has been criticized for the mission's failure to prioritize environments over other sectors (Gulati, 2021). In contrast, most of the 114 EU Smart City projects after 2010 are related to the environment and energy (Caragliu & Bo, 2019). This paper will examine whether smart city policy of India helps achieve environmentally sustainable development, specifically, green innovation.

In summary, previous research has focused on the impact of smart cities on innovation or on CO2 reduction in the developed country context, rather than on the environmental innovation effects in the developing country context. My research builds on existing work by exploring smart city policy's incorporate environmental effects on innovation in developing country, especially India.

## III. Data

### *3.1. Data sources*

In this research, data is measured at the state level by year. Panel data analysis was performed to examine the effect on the green innovation covering 26 Indian states within the period of 2001-2020.

The patent data from OECD REGPAT DATABASE (July 2021 edition) is used in this paper. The number of observations is 520 by state and year between 2001 and 2020. Four small states were dropped from the analysis: Daman and Diu (1 smart city out of 2 cities in total), Dadra and Nagar Haveli (1 smart city out of 2 cities in total), Chandigarh (1 smart city out of 1 city in total), Andaman and Nicobar Islands (1 smart city out of 3 cities in total) – because these states have a tiny number of smart cities but can be counted as states with a high proportion of smart cities. Green patent applications are selected and analysed in accordance with the ENV-TECH classification (OECD, 2016). OECD (2016) classified 95 green technologies by technological fields, grouping them into 9 families and 36 subgroups, to which International Patent Classification (IPC) and Cooperative Patent Classification (CPC) codes are assigned. For efficient analysis, I convert some presented IPC codes into CPC codes in accordance with a mapping table from the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) with a reference to the previous research by Perruchas et al. (2020). As neither code is available for "3. biodiversity protection and ecosystem health" on OECD (2016) ENV-TECH classification, only 8 families are used in this paper: environmental management, water-related adaptation, climate change mitigation associated with energy, greenhouse gases, transportation, buildings, waste management and production/processing of goods (shown in Table 1). A detailed classification with description is shown in Appendix 2.

The smart cities list was obtained from the official website of Smart Cities Mission (http://164.100.161.224/content/innerpage/cities-profile-of-20-smart-cities.php), and states list which has selected smart cities is from India Smart Grid Knowledge Portal (https://indiasmartgrid.org/smartcityproject.php).

**TABLE 1. Classification of environment-related technologies (ENV-TECH) (OECD, 2016)**

| Environmental policy objective | Patent search strategy | CPC class |
|---|---|---|
| Environmental health (human health impacts) | 1. Environmental management technologies | (IPC class) |
| Water scarcity | 2. Water-related adaptation technologies | (IPC or CPC class) |
| Ecosystem health and biodiversity | 3. Biodiversity protection and ecosystem health technologies | - |
| Climate change | 4. Climate change mitigation – Energy<br>5. Climate change mitigation – Greenhouse gases<br>6. Climate change mitigation – Transport<br>7. Climate change mitigation – Buildings<br>8. Climate change mitigation – Wastewater treatment or Waste management<br>9. Climate change mitigation – Production or processing of goods | Y02E<br>Y02C<br>Y02T<br>Y02B<br>Y02W<br>Y02P |

### *3.2. Variable construction*

***Green Innovation*** – In this research, patent data is used as a proxy for measuring innovation capabilities due to its property. Since patents are generally applied early in the research progress, they are considered a good indicator of inventive activities (Griliches, 1990).

In addition, the development of inventions is likely to be positively affected by patenting behaviors (Cohen et al., 2000; Ginarte and Park, 1997).

520 observations by state and year between 2001 and 2020 are examined in this paper. The dependent variable is green innovation which is estimated by the log of the number of environment-related patent applications to the PCT (Patent Cooperation Treaty) involved in each environmental technology in accordance with the ENV-TECH classification (OECD, 2016).

***Intensity of Smart City Policies*** – The independent variable is intensity of smart city policies measured by the proportion of selected smart cities in state s as a main independent variable in this paper or the number of smart cities engaged in Smart City Mission in state s. It allows the author to examine the impact of smart city policy involved in SCM and which engaged in green smart city projects. As 35 states include at least one smart city, among 37 states including Union Territories in India, a dummy variable for winning the smart city mission selection was not added. This paper used smart city list and the selection year of smart city data provided by the Ministry of Housing and Urban Affairs of India.

***Control variables*** – Initially, a set of variables that might present state characteristics were considered as control variables: a dataset of the population (Census 2011), GSDP (Gross State Domestic Product 2011-2012), unemployment rates (per 1000, Census 2011), and other variables that show the education level by states (2011). Unemployment rates (per 1000) in 2011-2012 are data according to usual status (ps) for each state or Union Territory covered both rural and urban areas. Variables for education status include enrolment in school in total as well as by gender.

### *3.3. Descriptive statistics*

Table 2 shows descriptive statistics of variables used in this paper at the state-year level. As SCM was first announced in 2015, I present the summary statistics of the patent data from 2001 to 2011. Other statistics are based on the year of 2011. Before SCM has been launched (since 2015), each state in India had about 35.2 patent applications on average. While there was not any application in some states, 489 patents at most were applied to the PCT from one single state.

Table 3 shows the correlation between the two different intensity indicators of smart city policy and pre-treatment outcomes and baseline characteristics. None of the coefficients are found to be statistically significant, which implies that before the launch of SCM, pre-treatment outcomes and characteristics are not significantly different among states. Thus, I don't control for population, GSDP, unemployment rates, and educational status in my analysis.

**TABLE 2. Descriptive statistics**

| | Total States | | | | |
|---|---|---|---|---|---|
| | Obs. | Mean | Std. | Min. | Max. |
| | (1) | (2) | (3) | (4) | (5) |
| **PATENT (2001-2011)** | 286 | 35.238 | 76.575 | 0 | 489 |
| **Environmental PATENT (2001-2011)** | 286 | 7.500 | 18.580 | 0 | 137 |
| **Non-environmental PATENT (2001-2011)** | 286 | 27.773 | 59.448 | 0 | 372 |
| **Population (2011)** | 286 | 39,700,000 | 44,700,000 | 607,688 | 200,000,000 |
| **Economic status** | | | | | |
| GSDP (2011-2012) | 286 | 284,370.90 | 293,063.90 | 7,198.00 | 1,199,548.00 |
| Unemployment rates (per 1000, 2011) | 286 | 42.85 | 51.15 | 7.00 | 256.00 |
| **Education (2011-2012)** | | | | | |
| Enrolment in school (Class1-5), total | 286 | 4,601,194 | 5,982,252 | 78,775 | 29,000,000 |
| Enrolment in school (Class1-5), boys | 286 | 2,385,692 | 3,108,013 | 39,904 | 15,100,000 |
| Enrolment in school (Class1-5), girls | 286 | 2,215,502 | 2,875,399 | 38,871 | 13,900,000 |

**TABLE 3. Baseline characteristics by smart city status: Pre-treatment period**

| | | Correlation Coefficients | |
|---|---|---|---|
| | Mean | The number of smart cities in state s | smart cities/total cities in state s |
| | (1) | (2) | (3) |
| **PATENT (2001-2011)** | 35.238 | 0.475 | 2.614 |
| | [76.575] | (0.426) | (1.764) |
| **Population, 2011** | 39,700,000 | -0.044 | 0.016 |
| | [44,700,000] | (0.069) | (0.286) |
| **Economic status** | | | |
| GSDP, 2011-2012 | 284,370.90 | 3.061 | -1.269 |
| | [293,063.9] | (3.445) | (14.262) |
| Unemployment rates (per 1,000), 2011 | 42.85 | -0.630 | 8.126 |
| | [51.15] | (7.816) | (32.353) |
| **Education** | | | |
| Enrolment in school (Class1-5), total, 2011 | 4,601,194 | 0.499 | -0.227 |
| | [5,982,252] | (0.425) | (1.758) |

*Notes: significant at 1% level ***, 5% level **, 10% level *.*
*Standard deviations are reported in [ ], and Standard errors are presented in ( ).*
*Population, Economic status, and Education of Column (2), (3): in millions. Scale was changed as coefficients were not visible.*

## IV. Empirical Strategy

To answer research questions of this paper, difference-in-differences method is employed. Specifically, the outcomes for states that were heavily affected by the smart city policy are compared with the outcomes for states that were not considerably affected.

The canonical difference-in-differences compares the change in outcomes for a treatment group before and after the treatment to one for a control group. However, among 37 states including Union Territories in India, 35 states include at least one smart city. In other words, nearly all states are treated to some extent. To overcome this issue, I use continuous treatments with varying intensity instead of comparing outcomes between a treatment group and a control group. I employ 2 different continuous indicators, the proportion of smart cities in state s in year t and the number of smart cities in state s in year t.

Formally, the difference-in-differences model can be specified as a two-way fixed-effect linear regression model:

$$Y_{st} = \alpha + \beta Smart_{st} + \theta_s + \tau_t + e_{st} \quad (1)$$

where $Y_{st}$ is the outcome, in this case, the log of environmental innovation output in state s in year t. To see the change in the environmental-related patent activity more effectively, I compare it to the change of the log of total patent application and the change of the log of non-environmental-related patent application with the equation (1). After that, I peer into the change of environmental-related patent activity trends by narrowing it down to specific technology. $Smart_{st}$ is defined as an indicator for intensity of smart city policy measured by the number of smart cities in state s at year t, and the proportion of smart cities in state s at year t ((The number of smart cities in state s in year t / the total number of cities in state s) * 100), respectively. The coefficient of interest throughout the paper, β, is the difference-in-difference estimate of the effect of smart city policy. $\theta_s$ is a fixed effect unique to state s, $\tau_t$ is a time effect common to all states in period t. Finally, $e_{st}$ is a state time-varying error term. Standard errors are clustered at the state level.

## V. Results and Discussion

This section consists of three parts. First, the main results of the regression previously specified are presented to examine the effect on green innovation as a whole. Second, I peer into the change in environmental-related patent activity trends by examining each patent family of the ENV-TECH classification (OECD, 2016). Third, I investigate the effects on a much deeper level by narrowing it down to specific technology.

### *4.1. The Effect of Smart City Policy on Green Innovation*

To begin with, figure 3 illustrates the OLS relationship between the proportion of cities engaging in smart city policy and green innovation proxied by the environmental-related patent application, without including fixed effects. Figure 4 shows it by using the logarithm of the environmental-related patent application. Each marker stands for the number of environmental patent applications in a corresponding state to each proportion of smart cities within 2001-2020, thus these scatterplots show positive, linear relationships between the smart city policy and green innovation.

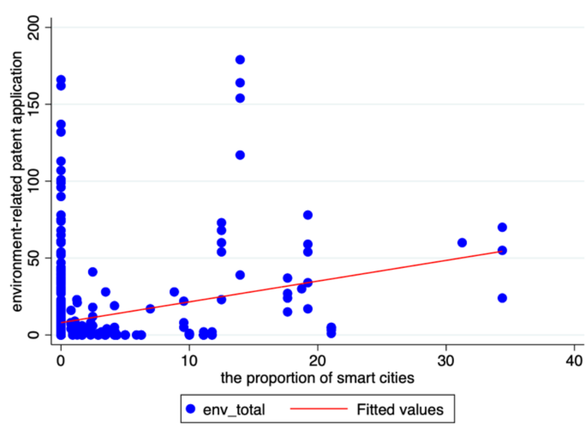


**Figure 3. OLS relationship between smart city policy (the proportion of smart cities) and environment-related patent**

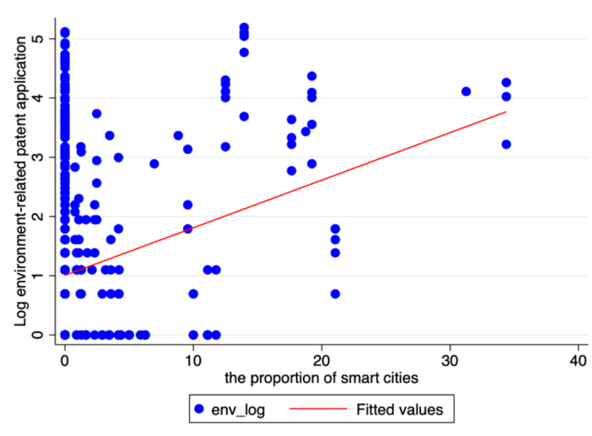


**Figure 4. OLS relationship between smart city policy (the proportion of smart cities) and log environment-related patent**

**TABLE 4. Regression results of the econometric model**

| | (1) total patent application (log) | (2) environmental-related patent application (log) | (3) non-environmental-related patent application (log) |
|---|---|---|---|
| **Panel A** | | | |
| the number of smart cities in state s | 0.016 | 0.084*** | 0.017 |
| | (0.024) | (0.019) | (0.022) |
| Observations | 520 | 520 | 520 |
| **Panel B** | | | |
| Proportion of smart cities in state s * 100 | 0.005 | 0.017** | 0.004 |
| | (0.014) | (0.007) | (0.014) |
| Observations | 520 | 520 | 520 |
| **Panel C: big states** | | | |
| Proportion of smart cities in state s * 100 | -0.020 | 0.029* | -0.023 |
| (Above the median of total number of cities) | (0.019) | (0.015) | (0.019) |
| Observations | 260 | 260 | 260 |
| **Panel D: small states** | | | |
| Proportion of smart cities in state s * 100 | 0.027 | 0.032*** | 0.027* |
| (Below the median of total number of cities) | (0.015) | (0.008) | (0.013) |
| Observations | 260 | 260 | 260 |
| State FE | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |

*Notes: significant at 1% level ***, 5% level **, 10% level *. Robust standard errors in parentheses, clustered at the state level.*

*Four small states were dropped from the analysis: Daman and Diu (1 smart city out of 2 cities in total), Dadra and Nagar Haveli (1 smart city out of 2 cities in total), Chandigarh (1 smart city out of 1 city in total), Andaman and Nicobar Islands (1 smart city out of 3 cities in total)*

*Panel B: The proportion of smart cities in state s = (The number of smart city in state s in year t / the total number of city in state s) * 100*

*Panel C&D: The median of total number of cities is 33*

Table 4 reports difference-in-differences (DID) regressions of patenting activity on smart city policy. To ensure the changes in the green innovation are not a general trend of the whole innovation but are specific effects, I compare the change of the environmental-related patent application (column 2) to the change of the total patent application (column 1) and to the change of non-environmental-related patent application (column 3) with the equation (1). The log of environmental patent application, the log of patent application and the log of non-environmental patent application are used as outcome variables, respectively.

The results are consistent in two different independent variables, which indicates that smart city policy had a positive impact on the environmental patent activity. In Panel A and B, the coefficients are positive and statistically significant in column (2), while coefficients for the log of total patent application (column 1) and the log of non-environmental-related patent application (column 3) are not. Panel A suggests that an increase of the number of smart cities in state s increased environmental patenting activity by 8.4%. With the main independent variable in this paper, a 10% increase in the proportion of smart cities in state s between 2001 and 2020 is associated with a 17% increase in environmental patent applications, as shown in Panel B in Table 4.

It is meaningful to peer into this further by dividing the whole sample into two groups with the median of total number of cities to compare the impact in big states to the impact in small states. The median is 33 cities. Although the coefficients of both sizes of states above and below the median are statistically significant, I find a more significant coefficient in small states. In small states, a 1% increase of the proportion of smart cities is associated with a 3.2% increase in environmental patent application at 1% level of significance (Panel C), whereas it is associated with increase by 2.9% at 10% level of significance in big states (Panel D) in column (2). This suggests that smart city policy had greater effects on the environmental patenting activity in small states, in comparison with the impact in big states with more than 33 cities. In huge states, a variety of factors can be far more influential than the smart city policy.

Overall, the results show that smart city policy has a positive impact on environmental patent activity. This increase in patent application is mostly the result of a sufficient increase in small states with 33 cities at most.

### *4.2. The Effect of Smart City Policy on Green Innovation on Patent Family Level*

Besides green innovation output as a whole, I further investigate the impact of each green patent family – (i) Environmental management technologies, (ii) Water-related adaptation technologies, and (iii) Climate change mitigation technologies. In this study, I skip "Biodiversity protection and ecosystem health technologies" to which CPC or IPC codes are not assigned in OECD (2016)'s ENV-TECH classification. Patent family 4-9 from table 1 are aggregated for the analysis into 'Climate change mitigation technologies' on account of their common objective.

The coefficients of smart city intensity are positive and statistically significant in all environment-related patent families in table 5, thus suggesting that smart city policy is positively correlated with innovation in all three sectors. In particular, a 10% increase in the proportion of smart cities in state s over the period of 2001-2020 is associated with a 22% increase in the patent application regarding environmental management technologies. Also, a 10% increase in the proportion of smart cities in state s increased the patent application regarding climate change mitigation technologies by 16%.

### *4.3. The Effect of Smart City Policy on Green Innovation on Specific Technology Level*

I narrow the results with strong effects above down to more specific technologies to examine the effect of smart city policy on environmental management technology innovation in table 6 and on climate change mitigation technology innovation in table 7.

Table 6 shows that most of the results for 5 detailed technologies of environmental management technologies are positive and significant. Specifically, the estimates in columns (1) and (3) demonstrate that a 10% increase in the proportion of smart cities in state s over the period of 2001-2020 is associated with a 22% increase in the patent application regarding air pollution abatement technology and 25% increase in the patent application regarding waste management technology, respectively.

Table 7 summarizes the estimations of the impacts on six technologies for climate change mitigation. Notably, the effect on the log of energy generation, transmission or distribution technologies is the strongest, as shown in column (1). The estimate for the log of transportation technologies is also positive and statistically significant in column (3). Indeed, the top 2 development sectors for the top 60 cities are Transport, and Energy and Ecology, comprising 78.9% of the SCM budget, according to Anand et al. (2018). They found that projects engaged with transportation take up about 25.3% of the whole budget while projects related to energy and ecology account for nearly 18%. To return to table 7 in this paper, none of the other outcome variables were significantly impacted by the proportion of smart cities in state s within the period of 2001-2020 – when the outcomes are the log of patent applications for capture, storage, sequestration, or disposal of greenhouse gases (column 2), buildings (column 4), wastewater treatment or waste management (column 5) and the production or processing of goods (column 6).

In sum, while all the environmental-related patent family outputs increased, innovation in regard to environmental management technologies and climate change mitigation technologies were significantly affected by the smart city policy in particular. More specifically, there were strong effects on patenting activity concerning air pollution abatement technology, waste management technology, and energy and transportation technologies for climate change mitigation.

**TABLE 5. Regression results of the econometric model for environmental-related patents**

| | (1) Environmental management technologies (log) | (2) Water-related adaptation technologies (log) | (3) Climate change mitigation technologies (log) |
|---|---|---|---|
| **Panel A** | | | |
| the number of smart cities in state s | .094*** | .043*** | .073*** |
| | (.018) | (.013) | (.016) |
| **Panel B** | | | |
| Proportion of smart cities in state s * 100 | .022*** | .009* | .016** |
| | (.007) | ( .005) | (.007) |
| Observations | 520 | 520 | 520 |
| State FE | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |

*Notes: significant at 1% level ***, 5% level **, 10% level *. Robust standard errors in parentheses, clustered at the state level. Four small states were dropped from the analysis: Daman and Diu (1 smart city out of 2 cities in total), Dadra and Nagar Haveli (1 smart city out of 2 cities in total), Chandigarh (1 smart city out of 1 city in total), Andaman and Nicobar Islands (1 smart city out of 3 cities in total)*

*Panel B: The proportion of smart cities in state s = (The number of smart city in state s in year t / the total number of city in state s) * 100*

**TABLE 6. Patents related to Environmental management technologies (env1)**

| | (1) Air pollution abatement (log) | (2) Water pollution abatement (log) | (3) Waste management (log) | (4) Soil remediation (log) | (5) Environmental monitoring (log) |
|---|---|---|---|---|---|
| **Panel A** | | | | | |
| the number of smart cities in state s | .082*** | .054* | .108*** | -.007*** | .052 |
| | (.009) | ( .029) | ( .017) | (.002) | (.032) |
| **Panel B** | | | | | |
| Proportion of smart cities in state s * 100 | .022*** | .018* | .025*** | -.001 | .024*** |
| | ( .005) | (.009) | ( .008) | ( .001) | ( .008) |
| Observations | 520 | 520 | 520 | 520 | 520 |
| State FE | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |

*Notes: significant at 1% level ***, 5% level **, 10% level *. Robust standard errors in parentheses, clustered at the state level.*

*Four small states were dropped from the analysis: Daman and Diu (1 smart city out of 2 cities in total), Dadra and Nagar Haveli (1 smart city out of 2 cities in total), Chandigarh (1 smart city out of 1 city in total), Andaman and Nicobar Islands (1 smart city out of 3 cities in total)*

*Panel B: The proportion of smart cities in state s = (The number of smart city in state s in year t / the total number of city in state s) * 100*

**TABLE 7. Patents related to Climate Change Mitigation Technologies (env4)**

| | (1) climate change mitigation (Y02E) - Energy | (2) climate change mitigation (Y02C) - GHG | (3) climate change mitigation (Y02T). - Transport | (4) climate change mitigation (Y02B). - Buildings | (5) climate change mitigation (Y02W) - Waste | (6) climate change mitigation (Y02P) - Production |
|---|---|---|---|---|---|---|
| **Panel A** | | | | | | |
| the number of smart cities in state s | .084*** | .020* | .047* | .006 | .019 | .023 |
| | (.022) | ( .012) | (.024) | (.015) | (.017) | (.019) |
| **Panel B** | | | | | | |
| Proportion of smart cities in state s * 100 | .024*** | .006 | .016* | .005 | -.006 | .000 |
| | (.007) | (.004) | (.008) | (.006) | ( .006) | ( .006) |
| Observations | 520 | 520 | 520 | 520 | 520 | 520 |
| State FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes: significant at 1% level ***, 5% level **, 10% level *. Robust standard errors in parentheses, clustered at the state level.*
*Four small states were dropped from the analysis: Daman and Diu (1 smart city out of 2 cities in total), Dadra and Nagar Haveli (1 smart city out of 2 cities in total), Chandigarh (1 smart city out of 1 city in total), Andaman and Nicobar Islands (1 smart city out of 3 cities in total)*
*The proportion of smart cities in state s = (The number of smart city in state s in year t / the total number of city in state s) * 100*

*4.4. Robustness checks – Event study specification*

Event study specification is employed as a robustness checks as well as verification if the common trend assumption is plausible. Formally, I estimate:

$$Y_{st} = \alpha + \sum_{t=2001}^{2020} \beta_t (Treat_s * dyear_t) + \theta_s + \tau_t + e_{st} \quad (2)$$

where $Y_{st}$ is the outcome, in this case the log of environment-related innovation output in state s in year t. $Treat_s$ is the proportion of smart cities in state s in year t. $dyear_t$ is year dummy. This specification allows to show visually that the number of environment-related patent applications in states that were heavily affected by the smart city policy and in states that were not considerably affected was the same before the launch of SCM. Figure 5, the average number of green patent applications of two areas track each other from 2010 to 2014, except for 2011. It shows that green patents in states that were heavily affected by the smart city policy does not exceed green patents in states that were not considerably affected in the absence of SCM, which is in line with the common trends assumption. After 2015, excess of the average number of environmental patent activity is observed. The graph converges temporarily in 2019 but starts to increase again.

To summarize, the coefficients show no differential trends between two areas before the introduction of SCM. The estimates after 2014 suggest that SCM increased environmental innovation on average.

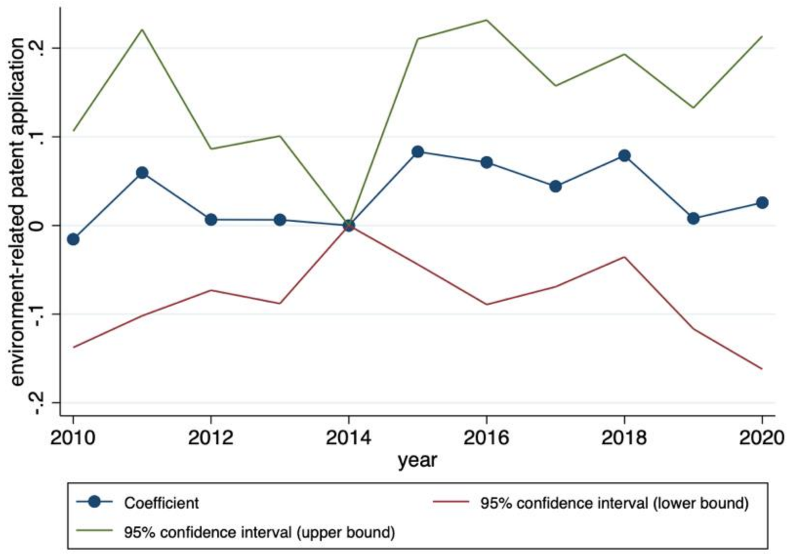


**Figure 5. Effect of SCM on patent activity: EVENT STUDY**

## VI. Conclusion

This paper elaborates on smart city policy and its environmental consequences in India. I provide empirical evidence of the causal effect of SCM on green innovation proxied by green patent application. In order to examine if being heavily affected by SCM promotes green innovation over the period of 2001-2020, I employed a difference-in-differences estimation to the state-level panel data. The outcomes for states that were heavily affected by the smart city policy are compared with the outcomes for states that were not considerably affected.

As identified in the results, smart city policy plays an important role in environmental innovation. The main findings in this study showed that smart city policy encouraged environmental patent activity. This increase in patent application is primarily the result of a sufficient increase in small states which have 33 cities at most. Besides green innovation output as a whole, I further showed that an increase in the smart city intensity led to significant increase in each green patent family – (i) Environmental management technologies, (ii) Water-related adaptation technologies, and (iii) Technologies for Climate change mitigation. In particular, there were strong effects on patenting activity concerning air pollution abatement technology, waste management technology, and energy and transportation technologies for climate change mitigation.

Given that the top two invested sectors of SCM are transport and energy, my empirical analysis implies that designing smart cities that focus on environmental influence is crucial. Indian government invested USD 801.64 bn in the transport sector and USD 395.13 bn in the energy sector across 37 states/union territories, according to the Ministry of commerce and industry (https://indiainvestmentgrid.gov.in/schemes/smart-city-mission). Moreover, SCM embraces many environmental projects. As developing countries tend to build smart cities by building massive infrastructure, it is important to put in place smart city policy that can lead to sustainable outcomes in order not to waste budgets.

This study is not free from limitations. First, it examines the effects on patent activity which shows one facet of green innovation. It seemed the best way to see the outcomes of smart city policy considering the progress of many SCM projects has been delayed so far. The study may be extended by investigating environmental, innovative performance led from adaptation of new technologies when SCM completed all projects, such as amelioration of water management system. Secondly, this research analyses the impact of smart city policy until 2020, which is five years after the launch of SCM. As the environmental sustainability is affected constantly, further study could be conducted for a long term. Third, this study measured green innovation with environment-related patent activity. However, not only green technologies classified by OECD but also other technologies can help to improve the environment or mitigate the climate change impacts. In the long term, it would be possible to identify which technologies affect environment and their own purpose simultaneously. In a future study, it would be useful to investigate long-term changes caused by smart city policy.

**References**

Agencies. (2017, October 31). August mineral output up 9.4%, valued at ₹18,015 cr. *Millenium Post*. http://www.millenniumpost.in/business/august-mineral-output-up-94-valued-at-18015-cr-268832?infinitescroll=1

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., & Airaksinen, M. (2017). What are the differences between sustainable and smart cities? *Cities*, *60*, 234–245. https://doi.org/10.1016/J.CITIES.2016.09.009

Anand, A., Sreevatsan, A., & Taraporevala, P. (2018). *An overview of the smart cities mission in India*. Centre for policy research, India.

Caragliu, A., & del Bo, C. F. (2019). Smart innovative cities: The impact of smart city policies on urban innovation. *Technological Forecasting and Social Change*, *142*, 373–383. https://doi.org/10.1016/J.TECHFORE.2018.07.022

Carvalho, L. (2015). Smart cities from scratch? A socio-technical perspective. *Cambridge Journal of Regions, Economy and Society*, *8*(1), 43–60. https://doi.org/10.1093/CJRES/RSU010

Chen, Y., Ardila-Gomez, A., & Frame, G. (2017). Achieving energy savings by intelligent transportation systems investments in the context of smart cities. *Transportation Research Part D: Transport and Environment*, *54*, 381–396. https://doi.org/10.1016/J.TRD.2017.06.008

Chopra, R. (2016). Environmental degradation in India: causes and consequences. *International Journal of Applied Environmental Sciences*, *11*(6), 1593-1601. http://ripublication.com/ijaes16/ijaesv11n6_21.pdf

Cohen, W.M., Nelson, R.R., Walsh, J.P., 2000. Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). Working Paper. *National Bureau of Economic Research.* https://doi.org/10.3386/ w7552

Deshmane, Akshay. (2021, November 10). How a just transition can make India's coal history. *BBC*. https://www.bbc.com/future/article/20211103-india-how-a-just-transition-can-make-coal-history

Fernández Fernández, Y., Fernández López, M. A., & Olmedillas Blanco, B. (2018). Innovation for sustainability: The impact of R&D spending on CO2 emissions. *Journal of Cleaner Production*, *172*, 3459–3467. https://doi.org/10.1016/J.JCLEPRO.2017.11.001

Ginarte, J.C., & Park, W.G. (1997). Determinants of patent rights: a cross-national study. *Res. Policy 26* (3), 283–301. https://doi.org/10.1016/s0048-7333(97)00022-x.

Glasmeier, A., & Christopherson, S. (2015). Thinking about smart cities. *Cambridge Journal of Regions, Economy and Society*, *8*, 3-12.

Griliches, Z. (1990). Patent Statistics as Economic Indicators: A Survey. Working Paper. *National Bureau of Economic Research*. https://doi.org/10.3386/w3301

Gulati, P. (2021, July 4). 49% of over 5,000 projects for smart cities unfinished as deadline nears. *Business Standard*. https://www.business-standard.com/article/current-affairs/nearly-49-of-smart-cities-incomplete-targets-distant-as-deadlines-loom-121062500133_1.html

Khadka, N. (2021, August 10). Climate change: The IPCC environmental warning India cannot ignore. *BBC News*. https://www.bbc.com/news/world-asia-india-58155294

Khattak, S.I., Ahmad, M., Khan, Z.U., & Khan, A. (2020). Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the

BRICS economies. *Environmental Science and Pollution Research, 27,* 13866–13881. https://doi.org/10.1007/s11356-020-07876

Mongo, M., Belaïd, F., & Ramdani, B. (2021). The effects of environmental innovations on CO2 emissions: Empirical evidence from Europe. *Environmental Science & Policy*, *118*, 1–9. https://doi.org/10.1016/J.ENVSCI.2020.12.004

OECD. (2011). *Towards green growth.*

OECD. (2016). *Patent search strategies for the identification of selected environment-related technologies (ENV-TECH).*

Perruchas, F., Consoli, D., & Barbieri, N. (2020). Specialisation, diversification and the ladder of green technology development. Research Policy, 49(3), 103922.

Seetharaman, G. (2019, October 6). Patents crucial for India to bridge tech gap with US and China. *The Economic Times*. https://economictimes.indiatimes.com/tech/internet/pending-patents-key-to-bridge-vast-tech-gap-with-us-china/articleshow/71458600.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

Shahbaz, M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO2 emissions: The role of technological innovations in China. *Energy Economics*, *86*, 104664. https://doi.org/10.1016/J.ENECO.2020.104664

Shruti, S., Singh, P. K., & Ohri, A. (2021). Evaluating the environmental sustainability of smart cities in India: The design and application of the Indian Smart City Environmental Sustainability Index. *Sustainability*, *13*(1), 327. https://doi.org/10.3390/SU13010327

Többelmann, D., & Wendler, T. (2020). The impact of environmental innovation on carbon dioxide emissions. *Journal of Cleaner Production*, *244*, 118787. https://doi.org/10.1016/J.JCLEPRO.2019.118787

Vanolo, A. (2014). Smartmentality: The smart city as disciplinary strategy. *Urban Studies*, *51*(5), 883–898. https://doi.org/10.1177/0042098013494427

World Intellectual Property Organization. (2020). *World Intellectual Property Indicators 2020*. Switzerland.

Wurlod, J. D., & Noailly, J. (2018). The impact of green innovation on energy intensity: An empirical analysis for 14 industrial sectors in OECD countries. *Energy Economics, 71*, 47–61. https://doi.org/10.1016/J.ENECO.2017.12.012

Xin, D., Ahmad, M., Lei, H., & Khattak, S. I. (2021). Do innovation in environmental-related technologies asymmetrically affect carbon dioxide emissions in the United States? *Technology in Society*, *67*, 101761. https://doi.org/10.1016/J.TECHSOC.2021.101761

Xu, N., Ding, Y., & Guo, J. (2020). Do smart city policies make cities more innovative: evidence from China. *Journal of Asian Public Policy*, 1-17. https://doi.org/10.1080/17516234.2020.1742411

Yadav, G., & Desai, T. N. (n.d.). A fuzzy AHP approach to prioritize the barriers of integrated Lean Six Sigma. https://doi.org/10.1108/IJQRM-01-2016-0010

Yigitcanlar, T., & Kamruzzaman, M. (2018). Does smart city policy lead to sustainability of cities? *Land Use Policy*, *73*, 49–58. https://doi.org/10.1016/J.LANDUSEPOL.2018.01.034

Yigitcanlar, T., & Kamruzzaman, M. (2018). Smart cities and mobility: Does the smartness of Australian cities lead to sustainable commuting patterns? *Journal of Urban Technology*, 1–26.

Yigitcanlar, T., Kamruzzaman, M., Buys, L., Ioppolo, G., Sabatini-Marques, J., da Costa, E. M., & Yun, J. H. J. (2018). Understanding 'smart cities': Intertwining development drivers with desired outcomes in a multidimensional framework. *Cities*, *81*, 145–160. https://doi.org/10.1016/J.CITIES.2018.04.003

Zhang, X., Bayulken, B., Skitmore, M., Lu, W., & Huisingh, D. (2018). Sustainable urban transformations towards smarter, healthier cities: Theories, agendas and pathways. *Journal of Cleaner Production, 173*, 1–10. https://doi.org/10.1016/J.JCLEPRO.2017.10.345

## Appendix A

### OLS relationship between smart city policy and total patent application

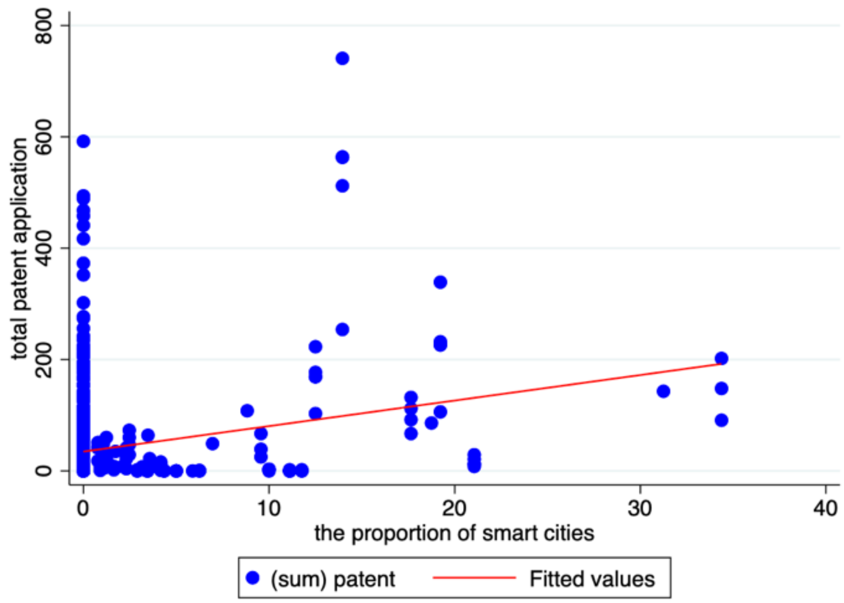


**Figure A1. OLS RELATIONSHIP BETWEEN SMART CITY POLICY (the proportion of smart cities) AND TOTAL PATENT**

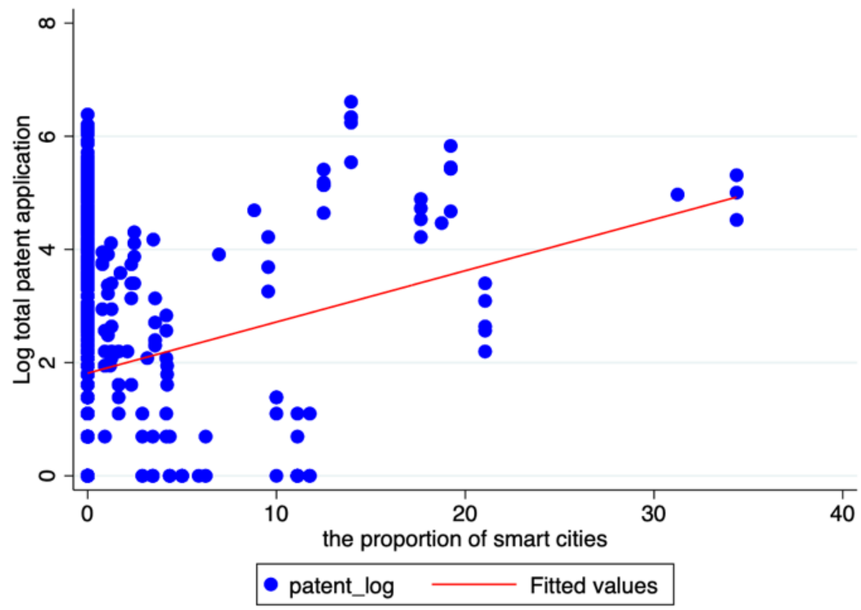


**Figure A2. OLS RELATIONSHIP BETWEEN SMART CITY POLICY (the proportion of smart cities) AND LOG TOTAL PATENT**

## Appendix B

### Table B1. Descriptive summary statistics: the proportion of smart cities in state s

| | state | The number of cities (2011) | The number of smart cities | The proportion of smart cities |
|---|---|---|---|---|
| 1 | Uttar Pradesh | 67 | 10 | 0.149253731 |
| 2 | Tamil Nadu | 32 | 11 | 0.34375 |
| 3 | Maharashtra | 43 | 6 | 0.139534884 |
| 4 | Madhya Pradesh | 35 | 7 | 0.2 |
| 5 | Gujarat | 34 | 6 | 0.176470588 |
| 6 | Karnataka | 26 | 5 | 0.192307692 |
| 7 | Rajasthan | 19 | 4 | 0.210526316 |
| 8 | Andhra Pradesh | 32 | 2 | 0.0625 |
| 9 | Bihar | 28 | 3 | 0.107142857 |
| 10 | Punjab | 237 | 3 | 0.012658228 |
| 11 | Telangana | 173 | 2 | 0.011560694 |
| 12 | West Bengal | 128 | 1 | 0.0078125 |
| 13 | Odisha | 24 | 1 | 0.041666667 |
| 14 | Goa | 38 | 1 | 0.026315789 |
| 15 | Assam | 110 | 1 | 0.009090909 |
| 16 | Chattisgarh | 84 | 3 | 0.035714286 |
| 17 | Haryana | 81 | 2 | 0.024691358 |
| 18 | Himachal Pradesh | 61 | 1 | 0.016393443 |
| 19 | Jharkhand | 95 | 1 | 0.010526316 |
| 20 | Uttarakhand | 115 | 1 | 0.008695652 |
| 21 | Kerala | 93 | 1 | 0.010752688 |
| 22 | Manipur | 29 | 1 | 0.034482759 |
| 23 | Meghalaya | 16 | 1 | 0.0625 |
| 24 | Tripura | 20 | 1 | 0.05 |
| 25 | Mizoram | 23 | 1 | 0.043478261 |
| 26 | Nagaland | 9 | 1 | 0.111111111 |
| 27 | Sikkim | 9 | 1 | 0.111111111 |
| 28 | Puducherry | 10 | 1 | 0.1 |
| 29 | Lakshadweep | 6 | 1 | 0.166666667 |
| 30 | Delhi | 8 | 1 | 0.125 |
| 31 | Arunachal Pradesh | 17 | 2 | 0.117647059 |
| 32 | Jammu and Kashmir | 69 | 2 | 0.028985507 |
| 33 | Daman and Diu (drop) | 2 | 1 | 0.5 |
| 34 | Dadra and Nagar Haveli (drop) | 2 | 1 | 0.5 |
| 35 | Chandigarh (drop) | 1 | 1 | 1 |
| 36 | Andaman and Nicobar Islands (drop) | 3 | 1 | 0.333333333 |

*Source:* The number of smart cities - The Ministry of Housing and Urban Affairs of India data