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What is the required minimum number of high-rise buildings above which the prevalence of melanoma decreases?

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Objectives: To explore the relationship between the prevalence of melanoma adjusted for age and the number of skyscrapers.

Study Design: The study is based on data from 50 US states and a 19-year period (1999–2017).

Method: An interesting contribution is the use of quadratic regression model, which permits non-monotonic modification with the number of skyscrapers in the state.

Results: For the 32 states with at least one skyscraper, results demonstrate an increase (a decrease) in anticipated prevalence of melanoma when number of skyscrapers is below (exceeds) 60 buildings.

Conclusion: Agglomeration of high-rise buildings, some of which are residential buildings, intensifies the shade effect and reduces reflection of radiation effect. Findings may be of assistance to public policy and city planners.

KEYWORDS

melanoma, skyscrapers, inverted U-shaped curve, prevalence, quadratic regression model

1 Introduction

Melanoma, a deadly multifactorial skin cancer, arises from genetic and environmental factors, with 60%–70% of cases linked to UV radiation exposure (Dzwierzynski, 2021). The rate of melanoma cases is rising more rapidly than that of any other cancer. The likelihood of developing melanoma in Western populations is approximately 2%, equating to one case for every 50 individuals (Dzwierzynski, 2021). Years of life lost due to metastatic melanoma in twelve Western nations ranges from 16.3 to 19.9 years for men, and from 19.0 to 23.1 years for women (Thiam et al., 2016). In Canada, it is estimated that 62.3% of melanoma cases in 2015 were due to UV exposure. Additionally, a 50% reduction in behaviors that increase UV exposure could potentially prevent around 11,980 melanoma cases by 2042 in Canada (O'Sullivan et al., 2019).

Two pathways for the development of melanoma include: 1) an early sun exposure pathway that leads to nevus formation and is exacerbated by intermittent intense sun exposure (including artificial light), and 2) a chronic exposure pathway in individuals sensitive to sunlight who gradually accumulate exposure in areas prone to future melanomas (Wang et al., 2001; Gandini et al., 2011; Armstrong and Cust, 2017; Gardner et al., 2019; Drexler et al., 2021).

Skyscrapers, defined as buildings exceeding 125 m, and tall structures are defining features of modern cities (Helsley and Strange, 2008; Ali and Al-Kodmany, 2012)[1]. Research across 183 US metropolitan areas indicates that the advantages of tall buildings for accommodating urban residents and businesses outweigh any negative externalities. Additionally, some studies suggest that skyscrapers enhance community feeling and perceived health benefits (Barr and Johnson, 2020). However, tall buildings have various environmental impacts; they can cast significant shadows that block sunlight from nearby properties. If these structures lack energy-efficient designs in their heating, cooling, and ventilation systems, they can be environmentally harmful. On the other hand, they may offer environmental benefits, such as access to sunlight and wind for solar panels and photovoltaic cells (Ali and Al-Kodmany, 2012).

Interestingly, the economic literature on skyscraper-related externalities is limited. Vertical transportation eliminates traffic jams, potentially enhancing worker interaction and knowledge sharing. Moreover, if taller buildings confer higher social status, worker productivity may increase (Barr and Johnson, 2020).[2] Shadows from skyscrapers are viewed as negative externalities, potentially decreasing surrounding property values by 2.6% for each hour of lost sunlight (Fleming et al., 2018).

In that context, Liu et al. (2021), who used a parametric method to evaluate the shading impact of surrounding buildings on energy demand. The shading calculations consider factors such as building parameters, inter-building spacing, layout, orientation, as well as the city's climate and geographic characteristics.

Lee et al. (2018) suggest that as climate change increases heat-related illnesses, seeking shade becomes crucial for protection. This study compares three urban shading strategies—building, tree, and umbrella shade—by measuring their impact on thermal comfort in London, Canada. Building shade was the most effective, followed by tree and umbrella shade, with effectiveness influenced by radiation blocking.

Despite the growing use of building performance simulation tools (BPSTs) in architecture, they remain largely absent from architectural curricula worldwide. Fernandez-Antolin et al. (2021) highlights their role in design decision-making, identifying gaps in architectural education and proposing improvements based on a literature review. The findings suggest that integrating BPSTs into the teaching process can bridge this gap, emphasizing the importance of energy modeling in early design stages. A framework for incorporating BPSTs into architectural practice is also presented.

This study aims to explore the correlation between the prevalence of new melanoma cases (adjusted for age) and the number of skyscrapers in 50 US states over 19 years (1999–2017), utilizing a quadratic regression model that captures non-linear relationships.

The contributions of this study are threefold.

1) Expanding the factors considered in urban planning policy to ensure that the design and construction of skyscrapers account for health issues such as melanoma, in addition to considerations like planning, transportation, sustainability, the environment, and others.
2) Traditionally, it was believed that skyscrapers block sunlight, which negatively impacts the environment. This article encourages a shift in perspective, suggesting that the shadow cast by skyscrapers can have a positive effect as well, not just a negative one.
3) The use of a quadratic model allows for either a U-shaped or an inverted U-shaped curve, with a global minimum or maximum, respectively (Chiang and Wainwright, 2005: 129–131). Given the potential variation in the trend of melanoma incidence with the number of skyscrapers, enforcing a consistently increasing or decreasing slope may be unjustified.

In this context, Arbel et al. (2022) found that projected melanoma incidence decreases as the number of skyscrapers increases. This study expands the model estimated by Arbel et al. (2022) by:

1. Relaxing the assumption of a monotonic and constant trend.
2. Conducting a robustness test that limits the sample to states with at least one skyscraper. This approach, which reduces the number of states from 50 to 32, is justified by the absence of tall buildings in many states.

The article proceeds with descriptive statistics in Section 2, methodology in Section 3, results in Section 4, and a conclusion in Section 5.

2 Descriptive statistics

Table 1 presents the descriptive statistics for the variables that are used in the empirical model. The dataset is organized as a panel, consisting of two groups of states. The first group includes a time series for all 50 US states, resulting in a total sample size of 905

1 It is important to note that there is no consensus in the literature regarding the definition of skyscrapers. This definition has evolved over time in response to advancements in construction technology (see O'Sullivan, 2012: 175–176 for a review). Initially, skyscrapers were defined as structures taller than 50 m, later adjusted to those exceeding 100 m. As construction technology continues to advance, further changes to this definition are expected.

2 It is important to note that the prevailing argument typically asserts that high-density construction undermines a sense of community. However, as Ali and Al-Kodmany (2012) highlight, several contemporary high-rise buildings in Beijing, China, feature a linked-hybrid design aimed at fostering a "sustainable" social life and community spirit. These complexes include numerous apartments, commercial spaces, hotels, cinemas, kindergartens, and underground parking, along with "streets in the air," or skybridges (see Ali and Al-Kodmany, 2012: page 402; Section 7.2).

TABLE 1 Descriptive statistics.

Variables	Description	Obs	Mean	Std	Min	Max
AgeAdjustedRate	Prevalence of melanoma adjusted for age	905	20.4506	5.5438	5.5	42.7
Skyscrapers	Number of skyscrapers in the state	905	15.4232	42.3986	0	267
(Year–1999)	Year in which the measure was taken	905	9.07	5.45	0	18
AgeAdjustedRate	Prevalence of melanoma adjusted for age	564	20.3828	5.2137	5.5	42.7
Skyscrapers	Number of skyscrapers in the state	564	24.7482	51.5292	1	267
(Year–1999)	Year in which the measure was taken	564	9.08	5.45	0	18

states × years. The second group comprises 32 states with at least one skyscraper, leading to a total sample size of 564 states × years.[3]

The average annual incidence of new melanoma cases, adjusted for age, ranges from 20.3828 to 20.4506 cases, with a standard deviation between 5.2137 and 5.5438 per 10,000 individuals. The minimum melanoma prevalence is 5.5 cases, while the maximum is 42.7 cases per 10,000 individuals (AgeAdjustedRate). Regarding skyscrapers, the average number per state is between 15.4232 and 24.7482, with a standard deviation of 42.3986–51.5292. Considering the requirement of at least one skyscraper per state, the increase from 15.4232 skyscrapers in the full sample of 905 states × years to 24.7482 in the smaller sample of 564 states × years is reasonable.

Appendix A details the number of skyscrapers by US state. While 17 states and the District of Columbia report zero skyscrapers, New York State has the maximum count of 267 skyscrapers. Lastly, the time variable (Year - 1999) encompasses 19 years from 1999 to 2017. For both samples, the mean (9.07–9.08) closely aligns with the median of 9. A symmetry test for both samples indicates that the null hypothesis of zero skewness cannot be rejected (p = 0.9022–0.9107).

Finally, the time variable (Year–1999) includes 19 years from 1999 to 2017. For both samples, the mean (9.07–9.08) resembles the median of 9. Indeed, a symmetry test for both samples reveals that the null hypothesis of zero skewness cannot be rejected (p = 0.9022–0.9107).

3 Methodology

Consider the following random-effect empirical model:

$$AgeAdjustedRate = \alpha_0 + \alpha_1 (Year - 1999) + \alpha_2 Skyscrapers + \alpha_3 Skyscrapers\_sq + \varepsilon \quad (1)$$

$$\varepsilon = D\vec{\beta} + \omega \quad (2)$$

Where *AgeAdjustedRate* is the prevalence of melanoma adjusted for age; *Year* is the year in which the measures took place ($Year = 1999, 2000, \cdots, 2019$);[4] *Skyscrapers* (*Skyscrapers_sq*) is the (squared) number of skyscrapers in the state; $\alpha_0, \alpha_1, \alpha_2$ are parameters; D is a matrix of dummy variables, where, with the exception of the base category, each column vector receives one for the state and zero otherwise; $\vec{\beta}$ is a column vector of parameters; and ω is the classical random disturbance term. This quadratic specification has the advantage of relaxing the assumption of monotonic increase or decrease. Differently put, it permits either a U-shaped or an inverted U-shaped curve with a global respective minimum or maximum (Chiang and Wainwright, 2005: 129–131).

Econometric textbooks stress the importance of panel data estimation in econometrics (e.g., Johnston and Dinardo, 1997: 391–395; Greene, 2012: 383–384). According to Johnston and Dinardo, 1997: “Instead, panel data estimation has grown in popularity because it has held out the promise of reducing a grave problem faced by most researchers: the lack of an adequate list of independent variables to explain the dependent variable” (page 395). Johnston and Dinardo, 1997 also note that when the true model is the random effect model with individual heterogeneity, *OLS* produces consistent but inefficient estimates. “In essence, the random effects model is one way to deal with the fact that T observations on n individuals is not the same as nT different individuals.” (Johnston and Dinardo, 1997, the bottom of page 391).

The random-effect regression accounts for serial correlation between the generic dummy variables for each US state and the main independent variables (see, for example, Wooldridge, 2009: 489–490).

To address the concern regarding the appropriate quadratic specification of the empirical model, we use the Ramsey’s RESET Procedure (Ramanathan, 2002: 270).[5] The test is based on two steps. The first step of the procedure is the construction of vector of predictions ($\hat{Y}$) from the model given in Equation 1. The second step is the incorporation of $\hat{Y}^2$, $\hat{Y}^3$ and $\hat{Y}^4$ in Equation 1

3 The 18 states without a single skyscraper are: Maine, New-Hampshire, Vermont, West Virginia, Alaska, Hawaii, Mississippi, Idaho, Montana, Wyoming, North Dakota, South Dakota, Rhode Island, Arizona, New Mexico, Utah, Kansas, District of Columbia.

4 Note that following the transformation ($Year - 1999$) the constant term becomes the baseline projected new melanoma cases adjusted for age at states without skyscrapers in 1999. For a formal derivation of this outcome, see, for example, Ramanathan, 2002: 147–148.

5 The Acronyms of RESET are Regression Specification Error Test.

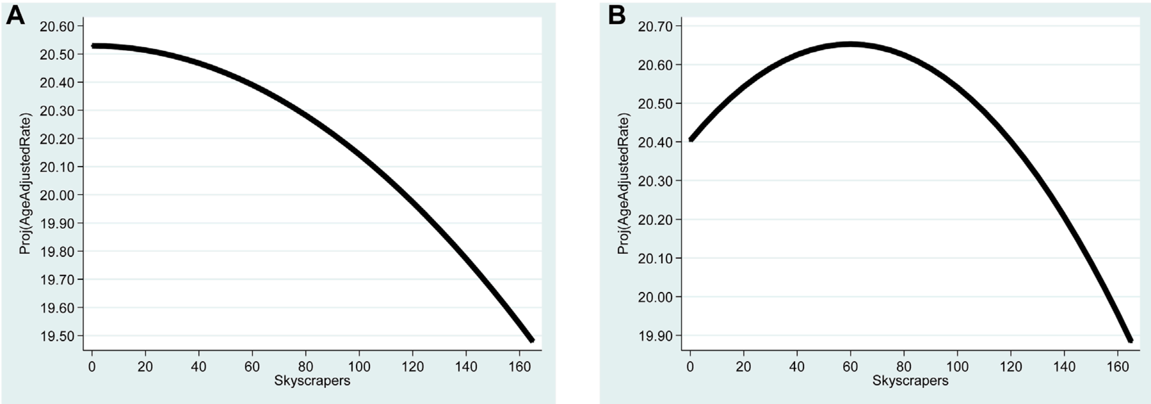

FIGURE 1
(A) Quadratic Model: Pooled Sample of States. Notes: The graph is based on the random effect regression outcomes of the pooled sample of 50 states given in column (2) of Table 2 **(B)**: Quadratic Model: 32 States With at Least One Skyscraper. Notes: The graph is based on the random effect regression outcomes given in column (1) of Table 3.

as additional independent variables and testing the joint null hypothesis that their coefficients equal zero. If the null hypothesis is not rejected, one could argue that the quadratic specification of the model in Equation 1 is appropriate. We apply this test to the random effect regression model.

4 Results

Figure 1A is based on the random effect regression outcomes of the pooled sample of 50 states, including the 18 states without skyscrapers. These are reported in Table 2 based on the empirical model given by Equations 1, 2. All the figures, estimation and statistical test outcomes were produced via the Stata statistical package software version 16.1. The multiple R-squared values are 0.1973–0.1975 in Table 2. The Wald Chi-squared statistics for regression significance (623.11–633.18) should be compared to the 1% critical values of 9.21–11.34. These results clearly reject the null hypothesis that all regression coefficients, excluding the constant term, are equal to zero.

Given that the null hypothesis of zero coefficient of the independent variable *Skyscrapers* is supported empirically (p = 0.1597), this variable was omitted from the empirical model, and the graph is based on column (2) of the table. The Ramsey's RESET Procedure supports the conclusion that the model with the time variable and the square number of skyscrapers in the state is appropriately specified at the 5% level ($p = 0.0609$).

Figure 1A depicts an inverted U-shaped graph (Chiang and Wainwright, 2005: 229–231) with a maximum point at (0, 20.52).[6] As the figure demonstrates, projected prevalence of new melanoma cases decreases monotonically from 20.52 per 10,000 persons in states without skyscrapers to 19.50 per 10,000 persons in states with 165 skyscrapers–an approximately 5% drop with 165 additional skyscrapers. The drop of projected melanoma prevalence is obtained at a decreasing pace of $2 \cdot 3.86 \cdot 10^{-5} = 0.00772\%$ per one additional skyscraper.[7]

Figure 1B is based on the random effect regression outcomes of the sample, that excludes the 18 states without any skyscraper and reported in Table 3. As previously noted, the random-effect model accounts for serial correlation between the generic dummy variables for each US state and the main independent variables (see, for example, Wooldridge, 2009: 489–490).

The Ramsey's RESET Procedure supports the conclusion that the full empirical model given in Equation 1 is appropriately specified at the 5% level ($p = 0.0675$).

Figure 1B depicts an inverted U-shaped graph (Chiang and Wainwright, 2005: 229–231) with a maximum point at (60, 20.65). The graph presents an attenuated 1.23% rise of projected melanoma new cases from 20.40 in states with one skyscraper to 20.65 per 10,000 persons in states with 60 skyscrapers. Above this maximum point, this rise is followed by a 3.77% drop to 19.90 projected new melanoma cases per 10,000 persons.

A potential explanation to this phenomenon is that on the one hand, the initial rise in the number of skyscrapers emanates from office buildings made of glass, which, in turn, elevates UV sun radiation (e.g., Wai et al., 2017). On the other hand, as the city evolves, more concrete residential skyscrapers are constructed, which provides more shade to pedestrians. Indeed, Wai et al. (2017) demonstrate that building reflection from reflective curtain walls could reach 23% of the un-obstructed solar total UV exposure rate at the ground level.

6 According to Chiang and Wainwright, 2005: 229–231, the general form of the quadratic function is: $y = ax^2 + bx + c$ ($a \neq 0$) with a second derivative equals to $2a$. Given that this derivative always has the same algebraic sign of the coefficient a, a U-shaped curve with a global minimum at $(\frac{-b}{2a}, \frac{-b^2+4ac}{4a})$ is obtained if $a > 0$, and an inverted a U-shaped curve with a, the global maximum at $(\frac{-b}{2a}, \frac{-b^2+4ac}{4a})$ is obtained if $a < 0$. It may also be readily verified that if $b = 0$, the global extremum point is $(0, c)$. In this specific case $c = 16.55 + 0.438 \cdot 9.07 = 20.52$.

7 Based on column 2 at the Table at the bottom of Figure 1A, $\hat{a} = -3.86 \cdot 10^{-5}$ and is statistically different from zero (p = 0.0007).

TABLE 2 Regression analysis: Pooled sample of states.

	(1)	(2)
Variables	AgeAdjustedRate	AgeAdjustedRate
Constant	16.51***	16.55***
	(<0.01)	(<0.01)
Year–1999	0.438***	0.438***
	(<0.01)	(<0.01)
Skyscrapers	0.00590	—
	(0.1597)	—
Skyscrapers_sq	-6.14×10^{-5}***	-3.86×10^{-5}***
	(0.0049)	(0.0007)
Observations	905	905
Number of Year	19	19
Calculated Wald Chi2 (3)/Wald Chi2 (3)	633.18***	623.11***
1% Critical Ch2(3)	11.34	—
1% Critical Ch2(2)	—	9.21
R-Square	0.1975	0.1973

Robust *p*-values are given in parentheses. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$. The Ramsey's RESET, Procedure rejects the hypothesis that the specification in column (2) is inappropriate at the 5% significance level ($p = 0.0609$).

Solar radiation is merely one of the many factors considered in urban planning. Other factors include green building practices, the area's development plans, its intended use (whether for offices, residences, or hotels), the developer's goals, municipal regulations, environmental considerations (such as proximity to the sea), taxation policies, climate conditions, the use of advanced technologies, construction requirements, and more.

5 Summary and conclusion

Melanoma is a potentially fatal and malignant multifactorial skin cancer resulting from an interplay between genetic predisposition and environmental exposure. An estimated 60%–70% of melanoma cases arise from ultraviolet radiation from sunlight (Dzwierzynski, 2021). The incidence of melanoma is increasing at a faster rate than any other malignancy and is linked to significant years of life lost (Thiam et al., 2016; O'Sullivan et al., 2019).

This study aims to investigate the relationship between the prevalence of newly diagnosed melanoma cases adjusted for age and the number of skyscrapers, using data from 50 US states over a 20-year period (1999–2017). The research hypothesis posits that particularly tall buildings cast long shadows, obstructing sunlight and UV radiation. A noteworthy aspect of this study is the application of a quadratic regression model, allowing for a non-monotonic relationship with the number of skyscrapers in each state.

Findings indicate an inverted U-shaped curve, showing an initial rise in projected new melanoma cases with an increasing number of skyscrapers up to 60, followed by a sharp decline between 60 and 165 skyscrapers. One possible explanation is that the initial increase in skyscrapers, primarily glass office buildings, enhances UV radiation exposure (see Mehaoued and Lartigue, 2019). As urban development progresses, more concrete residential skyscrapers emerge, providing greater shade and reducing UV radiation.

The study's results indicate an inverted U-shaped relationship, with an increase in melanoma prevalence associated with up to 60 skyscrapers, followed by a decline as the number rises from 60 to 165. This trend may be due to the initial rise in glass-clad office buildings increasing UV radiation. Initially, while these buildings create shadows, their glass facades also reflect UV light (Mehaoued and Lartigue, 2019). As cities develop, residential and mixed-use buildings typically replace commercial structures, creating a clustering effect. These residential towers often feature concrete or steel facades, which provide more shade and reduce UV exposure (Wai et al., 2017; Mehaoued and Lartigue, 2019).

On the one hand, the initial rise in the number of skyscrapers emanates from office buildings made of glass, which, in turn, elevates UV sun radiation (e.g., Wai et al., 2017). On the other hand, as the city evolves, more concrete residential skyscrapers are constructed, which provides more shade to pedestrians. Indeed, Wai et al. (2017)

TABLE 3 Regression analysis: 32 states with at least one skyscraper.

	(1)	(2)
Variables	AgeAdjustedRate	AgeAdjustedRate
Constant	16.72***	16.82***
	(<0.01)	(<0.01)
Year–1999	0.406***	0.406***
	(<0.01)	(<0.01)
Skyscrapers	0.00832*	—
	(0.0676)	—
Skyscrapers_sq	$-6.95 \times 10^{-5***}$	$-3.81 \times 10^{-5***}$
	(0.0048)	(0.0005)
Observations	564	564
Number of Year	19	19
$\frac{-b[Skyscrapers]}{2b[Skyscrapers\_sq]}$	59.84 [29.51, 90.17]	— —

Robust *p*-values are given in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. The Ramsey's RESET, Procedure rejects the hypothesis that the specification in column (1) is inappropriate at the 5% significance level ($p = 0.0675$).

demonstrates that building reflection from reflective curtain walls could reach 23% of the un-obstructed solar total UV exposure rate at the ground level.

Ultimately, as demonstrated by Ali and Al-Kodmany (2012), high-rise office buildings in urban centers (where land prices are high and redevelopment is prominent) tend to be succeeded by high-rise residential structures. The concentration of high-rise buildings, including residential ones, amplifies the shading effect and diminishes the reflective radiation impact for two reasons: 1) compared to office high-rise buildings, residential structures generally reflect less radiation due to their lack of curtain walls, with concrete or steel-frame facades minimizing the overall glass surface area; and 2) the clustering of high-rise buildings enhances the shading effect (e.g., Ali and El-Kudami, 2012; Pietrzak, 2014; Wai et al., 2017; Angela and Alexander, 2018; Mehaoued and Lartigue, 2019).

Our public policy recommendations are the following.

1. Health considerations should be integrated into the planning of every skyscraper in all aspects.
2. The shadow effect resulting from the construction of cluster of skyscrapers must be considered to help reduce the incidence of melanoma.

Urban planning involves numerous factors beyond solar radiation, including green building practices, development plans, intended land use (offices, residences, or hotels), municipal regulations, environmental considerations (such as proximity to the sea), taxation policies, climate conditions, construction requirements, technological advancements, and the developer's objectives. Recognizing this complexity, we plan to conduct a follow-up study.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.cdc.gov/skin-cancer/statistics/index.html.

Author contributions

YuA: Conceptualization, Formal Analysis, Writing – original draft, Writing – review and editing. YiA: Conceptualization, Formal Analysis, Writing – original draft, Writing – review and editing. AK: Conceptualization, Formal Analysis, Writing – original draft, Writing – review and editing. MK: Conceptualization, Formal Analysis, Writing – original draft, Writing – review and editing.

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