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# Renewal of waterways in a dense city creates value for residents

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# Abstract

Water sensitive practices can improve water quality and city livability, but the extent to which these practices improve the welfare of residents is not well researched. We contribute to knowledge in this area using Singapore's Active, Beautiful, Clean Waters (ABC Waters) Program as a case study. The program includes the renovation and integration of drains, canals, and reservoirs with the surrounding environment. To investigate impacts, we analyse real estate transactions within 2,000 m of 13 canals that were renovated between 2008 and 2016 as part of the ABC Waters program using both a difference-in-differences hedonic price model and a difference-in-differences exact matching model. We find the value of residential flats within 500 m of renovation sites increase by 1.6% (95% CI 1.0- 2.2%) after renovation projects. The empirical strategy and the placebo test results support a causal interpretation of the effect of canal renovation projects on flat prices. The uplift in value for flats within 500 m of canal upgrading projects is estimated to be between S$336 and S$504 million. This exceeds the combined costs of all ABC Waters projects and provides evidence that the benefits of urban waterway renewal projects are greater than the costs.

JEL: Q51, Q57, R31, Q25

Keywords: non-market valuation; hedonic model; water sensitive urban design; waterways; Singapore

# 1 Introduction

Many cities are built around waterways such as rivers and canals. Historically, waterways served functional roles, such as transportation, drainage, and water supply; but in modern times urban waterways are increasingly being reconstructed, renewed, or upgraded to improve liveability (Wong and Brown, 2009). Waterway reconstruction and renovation investment decisions can be supported by cost-benefit analysis; which in turn requires the quantification of the benefits of renovation projects. Some benefits of renovation can be easily quantified, for example, additional water supply and water quality improvement. Other benefits, such as improved aesthetic appeal or recreation benefits, are intangible and because they do not have market values are difficult to assess (Gunawardena et al., 2020).

Several empirical studies have quantified the capitalised value of waterways into home prices in urban settings (Anderson and West, 2006; Garrod and Willis, 1994; Jim and Chen, 2006; Luttik, 2000; Nelson et al., 2005; Rouwendal et al., 2017). Typically, these studies used cross-sectional data to identify the implicit price of proximity to urban waterways, and as such, the possibility that omitted variables may have resulted in biased estimates of the implicit price of amenity exist. A small number of studies have estimated the economic benefits of the ecological restoration of urban streams (Jarrad et al., 2018; Lewis and Landry, 2017; Polyakov et al., 2017). These studies use difference-in-differences and repeated sales approaches to capture the change in amenity due to restoration to overcome omitted variable bias issues. No studies estimating the non-market value of waterway renovation projects in densely populated urban environments have been identified in the existing literature.

In this paper, we estimate the effect of canal renovation projects in Singapore on the resale prices of residential properties near the renovation project. We argue that the change in property prices following a restoration project reflects the non-market value of the additional amenity generated by the renovation project, for the residents. Residential amenity benefit information can be used to evaluate past project investment decisions, and guide future water sensitive urban infrastructure investment decision making.

To overcome potential omitted variables bias issues, we use both a difference-in-differences hedonic model and a difference-in-differences exact matching model. Our results suggest that canal renovations, as implemented under the ABC Waters Program, increase the price of flats located within 500 m of a renovation project by 1.6% (95% CI 1.0- 2.2%), compared to the five years before the renovation. Falsification tests provide no evidence that the observed impact is due to differential growth rates of flat prices near the canals. As such, the falsification tests support a causal interpretation of the difference-in-differences and difference-in-differences exact matching estimates of the impact of canal renovations on the resale value of housing stock.

## 2 Background

In this section, we provide a brief review of the studies that have used the hedonic pricing method to estimate the non-market values of water sensitive projects. We also provide an overview of the public housing market in Singapore and the ABC Waters Program.

### *2.1 Valuing the renovation of urban waterways*

Environmental amenities are not directly traded in markets and as such do not have market prices. Environmental amenities are however implicitly purchased with market goods such as housing, and their values can be estimated using the hedonic pricing method (Rosen, 1974). The hedonic price method has been used to estimate the capitalised amenity value of public open space, and green and blue infrastructure (Fernandez and Bucaram, 2019; Geoghegan, 2002; Pandit et al., 2014; Panduro et al., 2018). Nicholls and Crompton (2017) reviewed studies that used the hedonic pricing method to estimate the value of proximity to rivers, canals, and other waterways on residential property values and identified several studies that estimate the amenity benefit of proximity to canals via the change in urban residential property prices (Bonetti et al., 2016; Garrod and Willis, 1994; Luttik, 2000; Nelson et al., 2005). These studies find that proximity to canals has a positive impact on house prices. Additionally, Boscacci et al. (2017) used cross-sectional data to measure the value associated with potential reconstruction ("daylighting") of the sections of an ancient urban canal flowing underground in Milan. The prices of the apartments within 500 m of open sections of the canal were €1,197 per square metre lower, while apartments with a view of the open sections of the canal were associated with a premium of €1,120 per square metre.

There are several studies that have used the hedonic price method to value the restoration or renovation of waterways. Using a cross-section database, Streiner and Loomis (1995) found that relative to areas where streams were not restored, property prices are 3% to 13% higher in areas with restored streams. In contrast, Mooney and Eisgruber (2001) found that the value of streamside residential properties in Oregon were lower, when a riparian buffer is planted with trees.

With "traditional" hedonic price model specifications there are multiple factors that can impact property values that, due to lack of data, are not explicitly incorporated into the model as covariates. For such models, omitted variable bias is always a potential concern. Within the hedonic price framework, the potential bias due to omitted variables can be mitigated through the use of quasi-experimental methods such as repeated sales, regression discontinuity designs, or difference-in-differences models (Bishop et al., 2020; Greenstone and Gayer, 2009).

Relevant to the current context, Lewis and Landry (2017) used the difference-in-differences (DiD) hedonic pricing method to evaluate the impact of river restoration achieved due to the removal of a dam in Maine, USA on property prices. Due to improvements in water quality and river amenities such as water views and fishing quality, the disamenity of water proximity decreased following the restoration. To estimate the non-market value of an urban drain restoration project in Perth, Western Australia, Polyakov et al. (2017) analysed repeated sales of residential properties. Controlling for other factors, the authors found homes within 200 m of the restoration site increased in value, on average, by 4.7%, once the restored area became fully established. Finally, Jarrad et al. (2018) used a repeat-sales model to investigate the effect of urban stream restoration projects in Oregon, USA on the price of nearby single-family residential properties. They found that properties closest to stormwater, floodplain, and revegetation projects experience a positive effect during different project phases.

### *2.2 Public Housing in Singapore*

Singapore is a city-state of 719 km$^2$, with a population of 5.6 million (Department of Statistics Singapore, 2016). As it owns and sells most of the land, the Government of Singapore plays a significant role in the domestic real estate market. The Government also is the provider of key infrastructure and has a strong tradition of spatial planning. The Housing & Development Board (HDB), a statutory board under the Ministry of National Development, is responsible for the planning and development of Singapore's housing estates and is the dominant provider of housing stock. The majority of resident households (80%) live in HDB dwellings, most of which (90%) are owned on 99-year leasehold terms (Department of Statistics Singapore, 2016). The remaining residential households live in private condominiums and apartments (14%) and landed properties (5%) developed by the private sector.

HDB housing is relatively uniform in design, and larger developments of high-rise flats typically consist of 10 to 20 storeys. Recently, however, building heights have risen to as high as 50 storeys in some areas. HDB determines the sale price of new HDB dwellings, and most HDB dwellings have a minimum occupation period of 5 years before they can be resold. In the resale market, prices are determined through buyer-seller negotiations, supported by professional valuations. In this study, we use HDB resale transactions because they constitute the majority of the Singapore housing market, are relatively homogenous, and prices are determined through buyer-seller negotiations in a market setting.

To improve the quality of aged HDB housing stock, the Government has implemented a series of upgrade and improvement programs. The Main Upgrading Programme (MUP) started in 1992 and was subsequently absorbed into the Home Improvement Programme (HIP) in 2007. Both MUP and HIP improve flats within whole HDB blocks (works include, for example, repair of concrete, upgrading electric wiring, replacing drainage pipes, bathroom upgrades, etc.) and improve the living environment without the need to move out. The Interim Upgrading Programme (IUP), replaced in 2007 by the Neighbourhood Renewal Programme (NRP) focuses on improvements to the shared areas of HDB blocks and precincts (e.g. playgrounds, landscaping, seating areas, and sheltered walkways).

### *2.3 Singapore Waterways and ABC Waters program*

Singapore receives about 2,400 mm of rain annually, yet, as there is limited space to store water on the island and no aquifers, it is a water-stressed city. Singapore obtains water from four sources: desalination; reuse of wastewater; imports from neighbouring Malaysia under a 100-year agreement that expires in 2061; and the local catchment (Tortajada, 2006). The local catchment provides about 20% of Singapore’s water, which is for a large part harvested from urbanised areas, including the Central Business District, through a complex system of 17 interconnected reservoirs and over 8,000 km of drains, canals, and rivers. Although ideas to integrate water bodies with urban development in Singapore originate in the 1980s, it was only in the early 2000s that there was a material shift in thinking on how to manage water resources (CLC, 2017). Rather than protecting local catchment water by keeping people away from the water body, the new paradigm was a people-centric approach in which citizens are involved in the protection and conservation of water and are encouraged to enjoy and value water (Buurman and Padawangi, 2017). Following this shift in thinking, in 2006, Singapore's National Water Agency (PUB) launched the ABC Waters Programme. The acronym ABC stands for Active – providing new community spaces and bringing people closer to water through recreational activities – Beautiful – transforming reservoirs and waterways into aesthetically pleasing lifestyle attractions that integrate well with other elements in the urban landscape – and Clean –improving water quality through holistic management of water resources by slowing down runoff, keeping water clean at source, while beautifying the landscape, and minimising pollution in the waterways through public education and by building people-water relationships (PUB, 2013).

Prior to March 2016, 32 projects, costing around S$150 million (about US$107 million) had been carried out under the ABC Waters Program (Straits Times, 2016). Projects are diverse and include the construction of a wetland to cleanse runoff from a former landfill, a floating wetland in a reservoir, fishing decks and boardwalks along the reservoirs, and the conversion of a 3 km straight concrete drain into a meandering stream through a park. Of the 32 projects, 14 are canal upgrade projects. These projects are located in residential areas and involve the redevelopment of large concrete canals by adding bioswales and rain gardens that cleanse rainfall runoff from roadside drains before discharge in the canal; adding features such as footpaths, viewing decks and seating spaces; and softening the look of the canal through additional plantings, gabion walls, and boulders, amongst other features.

The ABC Waters Program is very similar to other developments in urban water management, such as Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS) and Low Impact Development (LID). However, it has a much stronger focus on the social and urban livability aspects of water in the city. Concerning urban water management, Brown et al. (2009) identified a six-stage transition from a Water Supply City to a Water Sensitive City. The transition involves a transformation from the provision of rigid ‘hard’ infrastructure such as sewerage schemes and channels to ‘soft’ and flexible infrastructure such as adaptive and multi-functional infrastructure, legislation, social relations, and the development of water sensitive behaviours. Through programs such as ABC Waters, Singapore has made a quick transition from a Drained City (stage three), focused on flood protection through drainage and channelisation towards a Water Sensitive City (stage six), addressing water-sensitive behaviours through the integration of water in the urban landscape and living environment of people (Buurman et al., 2021; Iftekhar et al., 2019). The value city residents place on this transition is, however, little reported on, which is something this study tries to address.

## 3 Data

Our analysis of the impact of canal renovations in Singapore uses four datasets. The first dataset contains the characteristics and resale prices of publicly built and privately owned flats sold between 1990 and 2021. The second data set is a spatial dataset of the canals renovated as part of the ABC Waters program. The third dataset contains details on the timing and type of renovation of the Housing & Development Board (HDB) blocks. The final dataset is a spatial dataset describing the location and opening dates of the Metro Rail Transit (MRT) stations.

Data on the resale value of HDB flats in Singapore from 1990 onwards are publicly available from the Singapore government's data portal (data.gov.sg/dataset/flat-resale-prices), and we obtained 861,369 records covering the period January 1990 to November 2021. The detail associated with each record includes: transaction date (year and month), resale price, address of the HDB block, a 3-storey interval for the location of the flat, floor area, flat model, the flat type (number of rooms), and the lease commence date. Each HDB block is a single building with a unique postal code and with units that, in many cases, share the same lobby. We adjusted prices to the base year of 2019 using the monthly consumer price index for accommodation obtained from the Singapore Government Data website (data.gov.sg/dataset/consumer-price-index-monthly). Standardisation in the construction approach means that HDB flats can be well described by the number of rooms and the flat model (Fesselmeyer and Liu, 2018). As we also have information on the specific HDB block, the approximate storey of the flat, and the floor area, we have information on all essential flat features. HDB blocks were georeferenced using Google Geocoding API.

Based on the description of ABC Waters projects at the PUB website (www.pub.gov.sg/abcwaters/explore) and physical visits to all sites, each ABC Waters project was categorised, and the canal upgrading projects selected. The extent of each project site was digitised using the knowledge obtained through the site visit, Google satellite images, and the point data file of ABC Waters locations obtained from the Singapore government's data portal (data.gov.sg/dataset/abc-waters-sites). Construction completion dates for renewal projects were obtained from media announcements or reports of the opening ceremonies or events. We were not able to find publicly available data on the commencement of all projects. However, based on the three projects for which we had this information, it takes 1.5 – 2 years to complete a typical project.

Spatial data on the location of MRT station and station opening dates were obtained from the Singapore government's data portal (data.gov.sg/dataset/master-plan-2014-rail-station) and Wikipedia (en.wikipedia.org/wiki/List_of_Singapore_MRT_stations). Information on the type and status of HDB upgrade and renewal activities implemented in particular blocks was obtained from the HDB website (services2.hdb.gov.sg).

For the analysis, we selected two samples. The main sample includes all flats sold within 2,000 m of canal renewal projects between five years before completion of a relevant project and five years after completion of the earliest relevant project (within 2,000 m of sale). We selected the 2,000 m radius of the buffers because it is consistent with the size of HDB planning areas. The area within 2,000 m from any renovated canal contains 270,750 observations or 32% of all resales between 1990 and 2021.

We used the completion date as a treatment date because projects advertisement or start dates were not publicly available for most projects. Such an approach is consistent with that used in Pope and Pope (2015), where it was shown that the impact of new Walmart stores on housing prices was better captured by using completion dates. Further, Polyakov et al. (2015) found that in the context of restoring a drain into a natural ecosystem, house prices could even decline in the first years after the project, and then increase only after the ecosystem has become established.

There are several reasons for selecting five years pre- and post-treatment periods. First, while we do not have information about the announcement or start of the construction for most projects, we know that typically it takes 1.5-2 years to implement a project. If the beginning of the construction can impact flat prices, five year pre-treatment periods would be sufficient to capture prices of flats not affected by an anticipation effect. The potential downside of using completion dates instead of the renovation start date is underestimating the effect of renovation. Second, we selected the five-year post-treatment period because we did not have more than five years of post-completion data for some projects. Finally, pre- and post-treatment periods need to be symmetrical.

We only included sales in HDB blocks that had sales before and after a relevant project's completion date. Sales of flat types with very few observations (1-room and multi-family) that combined represented less than 0.5% of the observation, were also excluded. The main sample contains 57,972 observations, or 21% of the observations within 2,000 m of any canal.

To perform a placebo test, we used falsified completion dates for each renewal project by shifting the dates by ten years before the actual date. We selected falsification of the completion date by ten years to ensure that the samples do not overlap.  The placebo test sample was selected using the same decision rules as the main sample but with the falsified completion dates. This sample contains 66,635 observations or 25% of the observations within 2,000 m of any renovated canal. Table 1 presents descriptive statistics for both samples. Figure 1 shows the location of the canals that underwent renovations, as well as the location of other waterways, year of canal renovation, HDB towns, and the boundaries of planning regions.

Table 1. Summary statistics

| | Main sample (N=57,972) | | Placebo test sample (N=66,635) | |
|---|---|---|---|---|
| Continuous variables | Mean | Std. Dev. | Mean | Std. Dev. |
| Sale price, 2020 adjusted, S$1000 | 395 | 135 | 323 | 129 |
| Range (min-max) | (115-1,136) | | (29-1,068) | |
| Floor area, square metres | 91 | 27 | 92 | 27 |
| Range (min-max) | (34-297) | | (28-280) | |

| Binary and categorical variables | | N | % | N | % |
|---|---|---|---|---|---|
| Sales within 0–250 m after canal upgrade | | 2,774 | 4.8 | 2,779 | 4.2 |
| Sales within 251–500 m after canal upgrade | | 3,015 | 5.2 | 3,249 | 4.9 |
| Sales within 501–750 m after canal upgrade | | 3,163 | 5.5 | 2,760 | 4.1 |
| Sales within 0–500 m after canal upgrade | | 5,789 | 10.0 | 6,028 | 9 |
| Sales within 500 m of the operating MRT station | | 20,070 | 34.6 | 17,219 | 25.8 |
| Sales after MUP or HIP completion before the sale | | 20,551 | 35.4 | 6,274 | 9.4 |
| Sales after NRP or IUP completion before the sale | | 18,753 | 32.3 | 11,793 | 17.7 |
| Flat type | 2 Room | 956 | 1.6 | 646 | 1 |
| | 3 Room | 24,633 | 42.5 | 29,189 | 43.8 |
| | 4 Room | 18,341 | 31.6 | 21,048 | 31.6 |
| | 5 Room | 9,968 | 17.2 | 10,179 | 15.3 |
| | Executive | 4,074 | 7.0 | 5,573 | 8.4 |
| Storey range | 01 to 03 | 12,453 | 21.5 | 13,991 | 21 |
| | 04 to 06 | 14,537 | 25.1 | 18,114 | 27.2 |
| | 07 to 09 | 13,462 | 23.2 | 16,104 | 24.2 |
| | 10 to 12 | 9,951 | 17.2 | 13,121 | 19.7 |
| | 13 to 15 | 3,859 | 6.7 | 3,271 | 4.9 |
| | 16 to 18 | 1,714 | 3.0 | 1,072 | 1.6 |
| | 19 to 21 | 935 | 1.6 | 603 | 0.9 |
| | 22 to 25 | 642 | 1.1 | 294 | 0.4 |
| | 26 and above | 419 | 0.7 | 65 | 0.1 |

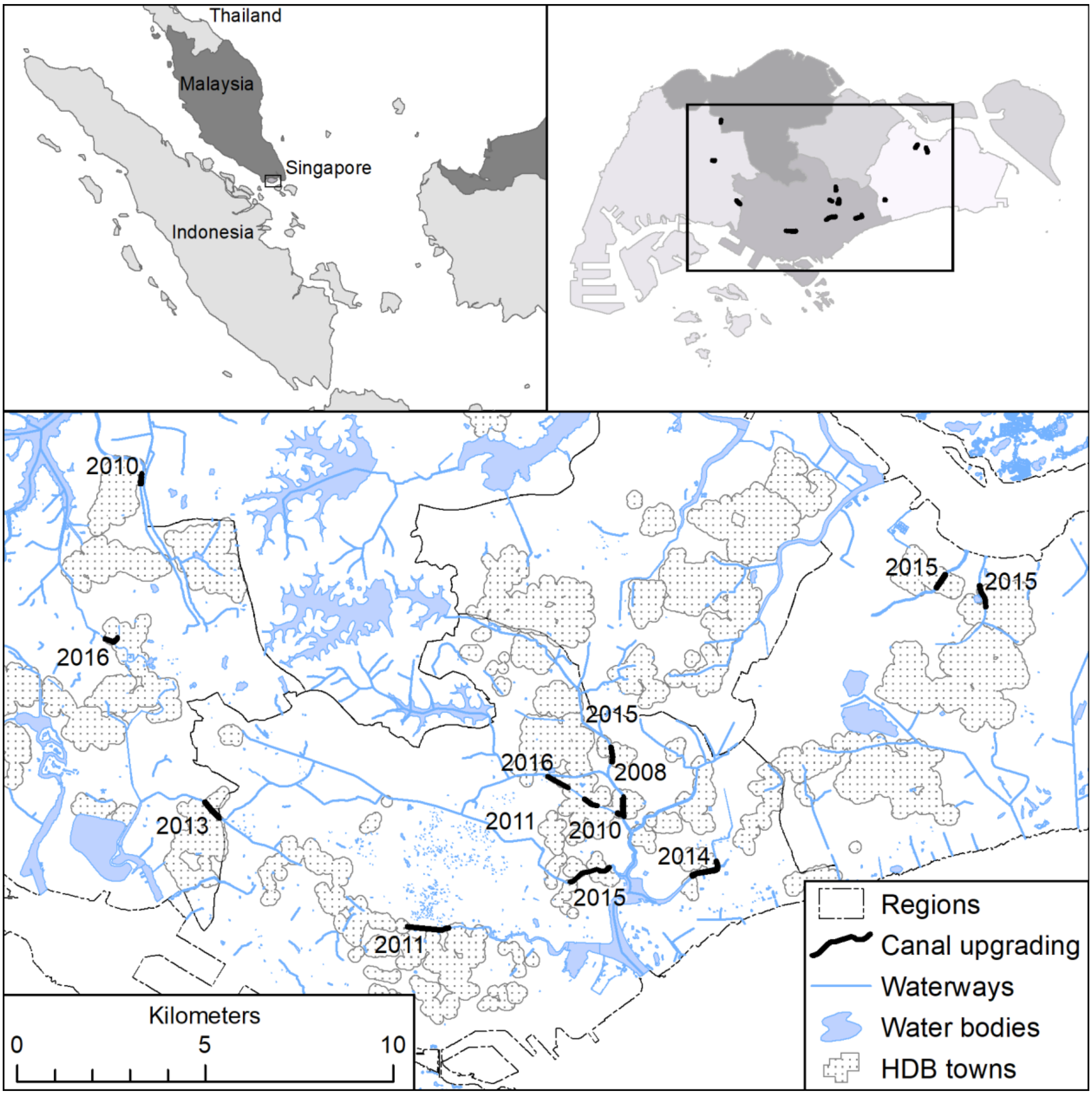

Figure 1. Study area and location of ABC canals. Numbers next to canals indicate years of renovation

# 4 Model and identification

## *4.1 Difference-in-Differences (DiD) hedonic model*

One quasi-experimental method that can be implemented within the hedonic price framework is the Difference in Differences (DiD) method (Ashenfelter, 1978; Bishop et al., 2020). Examples of hedonic-based DiD applications include Galster et al. (1999), and Pope and Pope (2015). The DiD approach involves estimating the average difference between the two potential outcomes as a function of the treatment. Because researchers cannot observe treatment units in both the treated and untreated state at the same time, identification requires a comparison of treated and untreated units. In the standard DiD design, units are observed before and after treatment and are grouped into treated and untreated. For this application, treatment means being located within a certain distance of the renovated canal.

We develop the model as follows. The indicator variable $D_{ik}$ is equal 1 if flat *i* belongs to the treatment group (is located within a certain distance) of canal renewal project *k*, and 0 otherwise. The variable $T_{ikt}$ indicates post-treatment, taking a value of 1 if the sale date *t* of flat *i* is after canal renovation project *k* was completed, and 0 otherwise. If $\ln P_{it}$ denotes the log of the price of a flat *i* resold in period *t*, the impact of renovating canal *k* on values of HDB flats can be modelled as:

$$\ln P_{it} = \alpha + \beta D_{ik} + \gamma T_{ikt} + \delta D_i T_{ikt} + \varepsilon_{it}, \tag{1}$$

where $\delta$ is the expected change of price of the treated group minus the expected change of price of the control group, and $\varepsilon_{it}$ is a zero-mean error term. Following Haninger et al. (2017):

$$\delta = \left( E\left(\ln P^{1}_{ikt_1} \mid D_i = 1\right) - E\left(\ln P^{0}_{ikt_0} \mid D_{ik} = 1\right)\right) - \left( E\left(\ln P^{0}_{ikt_1} \mid D_{ik} = 0\right) - E\left(\ln P^{0}_{ikt_0} \mid D_{ik} = 0\right)\right), \tag{2}$$

where the superscript indicates treatment status (1 if a flat is located near the canal and sold after the canal renovation, 0 otherwise); subscript $t_1$ indicates a time period after treatment; and subscript $t_0$ indicates a time period before the treatment. Identification in the DiD model relies on the assumption of common trends. In our case, this assumption means that flats in the treated group, if untreated, would exhibit the same change in price as flats in the untreated group:

$$E\left(\ln P^0_{ikt_1} \mid D_{ik} = 1\right) - E\left(\ln P^0_{ikt_0} \mid D_{ik} = 1\right) = E\left(\ln P^0_{ikt_1} \mid D_{ik} = 0\right) - E\left(\ln P^0_{ikt_0} \mid D_{ik} = 0\right). \tag{3}$$

To ensure the common trend assumption holds, we need to control for observable covariates $\mathbf{X}_{it}$ by adding them to the model:

$$\ln P_{it} = \alpha + \beta D_{ik} + \gamma T_{ikt} + \delta D_{ik} T_{ikt} + \mathbf{X}'_{it}\boldsymbol{\theta} + \varepsilon_{it}. \tag{4}$$

Three flat-level observable covariates are storey range, flat type, and floor area. Storey range and flat type enter the model as fixed effects and floor area as a log-transformed continuous variable.

To control for possible spatial autocorrelation and time-invariant unobservable locational characteristics, such as proximity to CBD or parks, we use HDB block spatial fixed effects. In a similar context, Heintzelman and Tuttle (2012), Livy and Klaiber (2016), and Polyakov et al. (2017) use house-level fixed effects when analysing sales of single-family houses where houses sold multiple times; while Agarwal et al. (2015) and Anundsen et al. (2021) use building fixed effects for hedonic analysis of flats and commercial premises in high-rise buildings. The block-level fixed effects in our study make the treatment group variable ($D_{ik}$) redundant. Some locational or block specific characteristics may change with time and violate the assumption of common trends. Within the context of this study, the opening of

MRT stations and HDB block-level upgrades or improvements are two factors that may lead to a violation of the common trend assumption because they affect the value of the flats (Agarwal et al., 2020; Fesselmeyer and Liu, 2018). To control for the impact of opening MRT stations, we include a variable indicating that an operating MRT station is located within 500 m of the HDB block. We selected a 500 m radius following the results of Fesselmeyer and Liu (2018) and Im and Hong (2018). To control for the impact of the block-level improvement programs, we included two binary variables that indicate completion of MUP or HIP programs and completion of IUP or NRP programs by the date of sale.

To control for unobservable factors influencing property market dynamics, such as the Global Financial Crisis, we include year-month temporal fixed effects. These fixed effects make the project-specific post-treatment variables ($T_{ikt}$) redundant, leaving only the interaction of project-specific post-treatment variables with the treatment group variables ($D_{ik}T_{ikt}$).

Some canal upgrade projects are close to each other, and there are flats located close to several canal renewal projects. In these cases, we assume that a flat is “treated” if it was sold after the completion of the earliest canal renewal project within distance *b*. For example, assume that a HDB block is located within 400 m of a canal renewal project completed in May 2010 and within 300 m of a canal renewal project completed in June 2012. Assuming that the impacts of the canal renewal projects extend to 500 m, we consider flats sold in this HDB block after May 2010 as treated.

The resulting empirical model is:

$$\ln P_{it} = \delta\left(\sum_{k=1}^{K} D_{ik}T_{ikt} < 1\right) + \mu m_{it} + \eta h_{it} + \nu n_{it} + \sigma \ln\left(s_i\right) + \lambda_{l(i)} + \varphi_{f(i)} + \tau_t + \beta_{b(i)} + \varepsilon_{it}, \quad (5)$$

where $\left(\sum_{k=1}^{K} D_{k(i)} T_{k(i)t} < 1\right)$ is an indicator of whether flat *i* is in a treatment group and is sold after completion of at least one canal renewal project. The $m_{it}$, $h_{it}$, and $n_{it}$ are dummy variables indicating, respectively, whether an MRT station is open within 500 m of the HDB block, an MUP or HIP project has been completed, and an IUP or NRP project has been completed before the sale of flat $i$, $s_i$ is the area of flat $i$, and $\mu$, $\eta$, $\nu$, and $\sigma$ are regression coefficients. The $\lambda_{l(i)}$, $\varphi_{f(i)}$, $\tau_t$, and $\beta_{b(i)}$ are, respectively, storey range, flat type, year-month, and HDB block fixed effects. Finally, $\varepsilon_{it}$ is a zero-mean observation-specific random error term.

### *4.2 Difference-in-difference exact matching model*

Estimates obtained using parametric quasi-experimental methods such as the DiD hedonic method may still be biased in some circumstances (Kuminoff and Pope, 2014). Bias may be introduced when methods based on panel variation fail to represent the slope of the hedonic price function, which can occur when the hedonic gradient shifts or when the composition of traded stock changes over time. Matching, which involves pairing treated flats with similar flats from a control group, can help to overcome this problem. With matching, the treatment effect is found by averaging across the price differences for matched pairs. The difference-in-difference matching estimator (DiDM) was proposed in Heckman et al. (1998); Heckman et al. (1997). The estimator is analogous to the standard DiD regression estimator but does not impose the linear functional form restriction when estimating the conditional expectation of the outcome variable (Blundell and Costa Dias, 2000; Smith and Todd, 2005). The DiDM can be implemented for longitudinal data when there are two measurements for treated and untreated subjects. It can also be implemented for repeated cross-section data when there are pre-treatment and post-treatment observations for treated and untreated groups, but it is impossible to identify two measurements for each treated subject (Smith and Todd, 2005).

For repeated cross-sections, we match each treated flat three times: to find the comparable flat in the treatment group before the treatment, as well as the controls before and after the treatment (Blundell and Costa Dias, 2000). We can find the effect of treatment on the treated as:

$$\delta_{DDM} = \sum_{i \in T_1} \left\{ \left( \ln P_{it_1} - \sum_{j \in T_0} W^{T}_{ijt_0} \ln P_{it_0} \right) - \left( \sum_{j \in C_1} W^{C}_{ijt_1} \ln P_{jt_1} - \sum_{j \in C_0} W^{C}_{ijt_0} \ln P_{jt_0} \right) \right\} w_i \qquad (6)$$

where $T_0$ is a set of treatment flats before the treatment, $T_1$ is a set of treated flats after the treatment, $C_0$ is a set of control flats before the treatment, $C_1$, is a set of control flats after the treatment, and $W^{G}_{ijt}$ is the weight attributed to flat *j* in group G at time *t* when comparing with treated flat *i*. Group G can be either control (G=C) or treatment (G=*T*). Finally, $w_i$ is the weight that accounts for the size of the treated sample.

We treat all attributes of flats as categorical variables and use exact matching. Flats located within distance *d* (for example, 500 m) from the canals are in the treatment group. Flats located outside of the distance *d* from any of the canals are in the control group. We first match each treated flat in the treatment group $T_1$ to untreated flats in the treatment group $T_0$ by HDB block, storey range, flat type, and flat model. This matching may result in several matches for each treated flat. Next, we exact match each pair in the treated group with pairs of flats in the untreated group within 2,000 m by storey range, flat type, flat model, year and quarter of sale of the pre-treatment and post-treatment flats, as well as MRT and renovation status of the pre-treatment and post-treatment flats. The flats in the untreated group are selected from the buffer between 500 m and 2,000 m from a canal. Again, this may result in several pairs matched to each pre-treatment–post-treatment pair in the treatment group. The weights $W_{ijt}^{G}$ are based on the number of control group pairs matched to each treatment group pair and the number of pre-treatment flats matched to each treated flat in each treatment group pair. Because we use exact matching, $W_{ijt_0}^{T}$ is the inverse of the number of untreated flats *j* matching treated flat *i* in the treatment group, $W_{ijt_1}^{C}$ is the inverse of the number of control pairs matching the treatment pair *i*, and $W_{ijt_0}^{C}$ is the product of the two.

### *4.3 Placebo test for the common trend assumption*

The validity of the causal inference based on the DiD method assumes that without canal renovation projects, sales of flats in the treatment group and the control group would have shared the same price trends. We cannot test this assumption directly, but if the treatment and control groups do not share common price trends before the canal renovation projects, we would question this assumption. To test if treatment and control groups share the same price trends before the renovation projects, we implement a placebo test (Kawaguchi and Yukutake, 2017). The temporal extent of the available resale data allows us to conduct the placebo tests by including transactions between fifteen and five years prior to the dates of respective renovation projects and treat them as if the renovation projects were completed ten years before the actual completion dates. This approach allows us to check the validity of the identification assumption in both the difference-in-differences and the difference-in-difference exact matching estimator frameworks (Pope and Pope, 2015).

## 5 Results

### *5.1 Difference-in-Differences (DiD) hedonic results*

For this analysis, we select a subsample of the sales records with flats sold between five years before and five years after the renovation of any canal within 2,000 m. We only include the observations that have a comparable observation in the same HDB block before and after the renovation project. For example, we include the sale record of a 3-room flat on a 4-6 storey range in a specific HDB block after the renovation of the nearest canal only if similar sale(s) were recorded in this HDB block before the renovation.

We apply the difference-in-difference approach with four different model specifications (Table 2). Based on similar studies (Breunig et al., 2019; Fesselmeyer and Liu, 2018; Polyakov et al., 2017), our prior is that the extent of the influence of the renovation project is approximately 500 m from a canal. We test this assumption by estimating a model with a set of three 250 m buffers (0–250 m, 251–500 m, and 501–750 m) from the canals, interacted with the treatment dummy variable (Table 2, Model 1). The 0-250 m buffers include up to three rows of HDB blocks, and the 0-500 m buffers include up to seven rows of HDB blocks.

The results show flat prices in HDB blocks in the first two buffers increase by similar values, 1.7% and 1.4%, after the renovations of the canals. In comparison, the flat prices in HDB blocks in the 501–750 m buffer are not affected. These results support the use of 500 m as the extent of influence of a renovation project. Satisfied that 500 m is a sound buffer distance and that the effect is relatively uniform across the buffer, we then estimate a model with a single 500 m buffer (Table 2, Model 2). The estimated impact is 1.6%, the results are similar between the two models, but we prefer the simpler single buffer model. The results also indicate a positive impact on flat prices of HDB block upgrade projects and construction of an MRT station within 500 m from the HDB block. As expected, flat prices increase with floor area, the number of rooms, and storey level (Table A1 in the Appendix).

Table 2. Difference-in-difference estimation of the impact of canal renovation on the resale prices of residential flats and falsification test.

| Variables | Model 1 250, 500, 750 m buffers | Model 2 500 m buffer | Model 3 (placebo test) 250, 500, 750 m buffers | Model 4 (placebo test) 500 m buffer |
|---|---|---|---|---|
| Sale within 0–250 m after canal upgrade | 0.017 (0.004)*** | | -0.001 (0.009) | |
| Sale within 251–500 m after canal upgrade | 0.014 (0.005)*** | | -0.009 (0.009) | |
| Sale within 501–750 m after canal upgrade | -0.003 (0.005) | | -0.010 (0.010) | |
| Sale within 0–500 m after canal upgrade | | 0.016 (0.003)*** | | -0.004 (0.007) |
| Sale within 0–500 m from MRT station | 0.051 (0.005)*** | 0.052 (0.005)*** | 0.062 (0.016)*** | 0.062 (0.015)*** |
| Sale after MUP or HIP completed | 0.020 (0.004)*** | 0.020 (0.004)*** | 0.173 (0.010)*** | 0.173 (0.010)*** |
| Sale after IUP or NRP completed | 0.031 (0.004)*** | 0.032 (0.004)*** | 0.044 (0.005)*** | 0.044 (0.005)*** |
| log(floor area) | 0.624 (0.018)*** | 0.624 (0.018)*** | 0.736 (0.021)*** | 0.736 (0.021)*** |
| HDB block | X | X | X | X |
| Flat type | X | X | X | X |
| Storey range | X | X | X | X |
| Year-month | X | X | X | X |
| Clustering of std. errors | HDB block | HDB block | HDB block | HDB block |
| N | 57,972 | 57,972 | 66,635 | 66,635 |
| R2 | 0.959 | 0.959 | 0.941 | 0.941 |

Notes: Robust standard errors in parenthesis. ** $p < 0.05$; *** $p < 0.01$.

To test whether the increase in flat prices is due to the canal renovation projects or due to differential trends in flat prices and/or differences in the composition of the traded stock near canals relative to price trends and the composition of traded stock farther away from canals, we conduct a placebo test for the common trend assumption (Table 2, Model 3 and 4). We do this by re-estimating models 1 and 2 using false canals renovation dates. Specifically, we set the false renovation dates to ten years before the actual renovation date for each renovated canal and then use the same decision criteria for model estimation. For each false canal renovation project, we select observations within 2,000 m between five years before and five years after the falsified date of the renovation and exclude flat sales where there is no sale of similar flats in the same HDB block both before and after the renovation. The results indicate that placebo canal renovations do not impact flat prices, suggesting the common trends in flats belonging to the treatment and control groups. We interpret this result as providing no evidence that the positive effect of renovation projects in the base case models is due to differential flat price growth for flats close to canals relative to those far from canals.

We further test the robustness of our preferred model to the possibility of different price trends for regions and flat types. To test the robustness of the results to different price trends in the Singapore regions, we interact temporal fixed effects with region fixed effects (Table 3, Model 5). The magnitude of the coefficient is lower than in Model 2, and the plot of fixed effects suggests differences in price trends between regions (Figure B3 in Appendix B). To test the robustness of the results to different trends by flat type, we interact temporal fixed effects with flat type fixed effects (Table 3, Model 6). The magnitude of the coefficient is slightly higher than in Model 2, and the plot of fixed effects suggest differences in price trends between flat types (Figure B4 in Appendix B). Finally, we estimate a model with both interactions (Table 3, Model 7). The coefficients for the variable of interest is the same as in Model 2. Therefore, we conclude that Model 2 is the preferred model as it is simple.

Finally, we test whether the projects completions or project commencements are adequate treatment dates. While we assumed that the treatment date is project completion, there is a possibility that potential sellers and buyers have information about planned renovations or observe the commencements of the projects, and flat prices may increase in anticipation of canal renovations. We do not have data about the timing of the planning and construction of all projects as the projects were not widely announced in the media. However, we assume that the construction usually takes 1.5-2 years. In an alternative model, we assume that the commencement of the construction is two years prior to completion and use this date as a treatment date. We estimate model 2 with the treatment date shifted two years before the completion date (Table 3, Model 8). The estimated impact is about one-third lower than in Model 2, indicating that the completion date is a more appropriate treatment date than the commencement date, and Model 2 is our preferred model.

Table 3. Difference-in-difference estimation of the impact of canal renovation on the resale prices of residential flats with interactions of fixed effects and announcement date.

| Variables | Model 5<br>Year-month x Region FE | Model 5<br>Year-month x Flat type FE | Model 7<br>Year-month x Region FE and Year-month x Flat type FE | Model 8<br>Treatment date shifted two years earlier |
|---|---|---|---|---|
| Sale within 0 - 500 m after canal upgrade | 0.018 (0.003)*** | 0.012 (0.003)*** | 0.016 (0.003)*** | 0.010 (0.004)** |
| Sale within 0 - 500 m from MRT station | 0.033 (0.005)*** | 0.050 (0.004)*** | 0.042 (0.004)*** | 0.039 (0.010)*** |
| Sale after MUP or HIP completed | 0.029 (0.003)*** | 0.031 (0.003)*** | 0.038 (0.003)*** | 0.041 (0.004)*** |
| Sale after IUP or NRP completed | 0.025 (0.003)*** | 0.020 (0.003)*** | 0.017 (0.003)*** | 0.016 (0.004)*** |
| log(Floor area) | 0.622 (0.018)*** | 0.616 (0.018)*** | 0.614 (0.018)*** | 0.627 (0.017)*** |
| HDB block | X | X | X | X |
| Flat type | X |  |  | X |
| Storey range | X | X | X | X |
| Year-month |  |  |  | X |
| Year-month x Flat type |  | X | X |  |
| Year-month x Region | X |  | X |  |
| Clustering of standard errors | HDB block | HDB block | HDB block | HDB block |
| Num.Obs. | 57972 | 57972 | 57972 | 65020 |
| R2 | 0.962 | 0.966 | 0.968 | 0.956 |
| AIC | -145832.4 | -151638.7 | -154503.8 | -152607.8 |

Notes: Robust standard errors in parenthesis. ** $p < 0.05$; *** $p < 0.01$.

### 5.2 *Difference-in-difference exact matching results*

For the DiDM model, estimates of the average treatment effect of canal renovations are recovered from the quadruples of matched sales of flats: pre- and post-treatment in the treated group and pre- and post-treatment in the control group. We use a 500 m buffer from canals to define the treatment group. We define the control group as flats in HDB blocks located between 500 and 2,000 m from a canal renewal project. The pairs in the treatment group are matched with the pairs in the control group located no more than 2,000 m apart. Again, we conducted a falsification test by applying the DiDM estimator to the sample with the falsified dates of canal renovations, set to 10 years before the actual dates. For both the base case and the placebo test, we implement matching on discrete variables (HDB block, storey range, flat type, and flat model) and floor size of the flats.

Estimation results are presented in Table 4, and the estimated impact of canal renovations is an uplift in flat prices of 1.2%. Matching on the floor area of the flats in addition to the categorical variables reduces the number of matches and results in an effect size of 1.0%. The placebo test results show no significant impact of falsified canal renovation on flat prices, adding credibility to the findings.

Table 4. Difference-in-difference exact matching estimate results

| Model | No. treated | Estimates |
|---|---|---|
| Base case, matched by categorical variables | 1,758 | 0.012 (0.0024)$^{***}$ |
| Base case, matched by categorical variables and floor area | 1047 | 0.010 (0.0030)$^{***}$ |
| Placebo test, matched by categorical variables | 3,647 | 0.0004 (0.0041) |
| Placebo test, matched by categorical variables and floor area | 3,136 | 0.0006 (0.0019) |

Notes: Standard errors are in the parenthesis; *** $p < 0.01$.

## 6 Conclusions

Our paper is one of the first studies to estimate the monetary value of the amenity benefits of canal renewal projects in densely populated cities. We find that following the renovation of major drainage canals in Singapore, flat resale prices within 500 m of the renovation increase by 1.6% (95% CI 1.0- 2.2%). Various tests have shown that these estimates are robust. We interpret this uplift in flat prices as a measure of the increased value the renovation projects have created for the residents.

The estimated benefits of canal renewal projects are conservative as the estimates are mostly amenity value and recreational benefits. Renovation projects may provide other benefits, such as a range of biodiversity benefits and water management benefits, and so this estimated value represents only a portion of the benefits generated through these renovation projects. Another issue is related to the assumption that the benefits of canals renovation are capitalised in resale prices after the projects' completion dates. In reality, the benefits may be captured in transactions before project completion due to anticipation of the improved amenities or later, due to the delay in learning about amenity value that the renovation generates. Due to the absence of data, it was not possible to use the exact dates when information about the renewal of individual canals became available. As the best possible proxy, we have used five years before the completion date as a control period and five years after the completion date as a treatment period to capture the effect, even though the estimated effect would underestimate the true effect of renewal projects.

A natural follow up question is whether the estimated benefit outweighs the costs of a canal improvement project. There is limited publicly available information on the cost of the canal renovation projects. For several projects, the cost mentioned in the press also include costs that would have been incurred anyway as part of traditional drainage improvement works, and in some cases, also costs for renovation of adjacent parks. As such, we do not have sufficient information to conduct formal benefit-cost analysis, but we can make some comparisons of costs and benefits. The cost of the Kolam Ayer ABC Waters project, in which the traditional drainage improvement component is most likely minimal or absent, was reported as $2.5 million (Straits Times, 2008). Based on the average sales price per flat type and resale price increase between 1.0% and 2.2%, we estimate the uplift in value is between S$19.7 and S$43.3 million of the units within 500 m from the canal.[1] Similarly, for the S$2.2 million dollar ABC Waters project at St. George's Lane (Straits Times, 2011), the uplift is estimated to be between S$41.8 and S$91.9 million. These benefits are much larger than the costs of the projects and do not include the uplift in the value of non-HDB properties. The uplift in the value for all HDB flats within 500 m of canal upgrading projects is between S$280 and S$616 million. This is more than three times the costs of all ABC Waters projects, including projects other than canal upgrading, in 2016. On this basis, it is safe to conclude that the benefits of urban waterway renewal in Singapore, as implemented through the ABC Waters projects, have been greater than the costs.

Creating a water sensitive city involves investments in excess of those associated with creating a functional, drained, and sewered city. Investments in water-sensitive city infrastructure, however, also deliver benefits in addition to those of traditional hard infrastructure. Detailing these benefits in monetary terms, as we have done here, helps build confidence in the social value of such projects. This gives relevant government agencies the 'social licence' to embed water sensitive cities projects in the broader statutory planning process and integrate with other sectoral policies (Fogarty et al., 2021). Agencies could also use the non-market values in their formal investment decision-making process to find the optimal level of investment in canal renewal projects. Finally, the projects considered here are all public sector projects. It might be possible to design even more effective projects in collaboration with the private sector (Buurman et al., 2021). By demonstrating the value of

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[1] The number of flats by type (1-room, 2-room, etc.) within a 500 m buffer was tabulated and multiplied with their respective mean sales value and summed to calculate the total property value.

investing in water sensitive cities projects, it would be possible to attract private development sectors.

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