Quaderni del Premio «Giorgio Rota»

N. 11, 2023

Urban Economies as Complex Systems

Centro di Ricerca e Documentazione Luigi Einaudi
1963 - 2023

Con il sostegno di
Fondazione CRT

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Iniziativa realizzata con il sostegno di
Fondazione CRT

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Il Premio «Giorgio Rota»

L'intento del Premio «Giorgio Rota» è di riprendere l'attività di ricerca annualmente condotta dal Comitato / Fondazione Giorgio Rota prima della sua inclusione nel Centro Einaudi, sulla relazione tra il pensiero e l'agire economico e un aspetto (ogni anno diverso) del vivere in società, mantenendo vivo il ricordo e l'insegnamento dell'economista Giorgio Rota, uno dei primi animatori del Centro, prematuramente scomparso.

Dal 2012 il Centro Einaudi ha dunque raccolto questa eredità rinnovando la formula della ricerca: è stato perciò istituito questo premio annuale dedicato a giovani ricercatori, con una qualificazione accademica nei campi dell'economia, sociologia, geografia, scienza politica o altre scienze sociali. I paper possono essere presentati sia in italiano che in inglese, e non devono essere stati pubblicati prima della data della Conferenza Rota, l'evento pubblico nel quale i vincitori hanno modo di presentare il loro lavoro.

La prima edizione aveva per tema *Contemporary Economics and the Ethical Imperative* e la Conferenza Giorgio Rota si è tenuta presso il Centro Einaudi il 25 marzo 2013 con keynote speech di Alberto Petrucci, LUISS Guido Carli, Roma.

La seconda edizione è stata su *Creative Entrepreneurship and New Media con Conferenza* Giorgio Rota presso il Centro Einaudi, 14 aprile 2014 e keynote speech di Mario Deaglio, Università di Torino.

La terza edizione ha analizzato il tema *The Economics of Illegal Activities and Corruption*, con Conferenza Giorgio Rota presso il Centro Einaudi, 15 giugno 2015. Keynote speech di Friedrich Schneider, Johannes Kepler University (Linz, Austria).

La quarta edizione verteva su *The Economics of Migration*. Il 20 giugno 2016 si è tenuta la Conferenza Giorgio Rota presso il Campus Luigi Einaudi, in collaborazione con FIERI. Keynote speech di Alessandra Venturini, Università di Torino. Dal 2016 inoltre il Premio è sostenuto dalla Fondazione CRT.

La quinta edizione trattava di *Economic Consequences of Inequality*, e i saggi vincitori sono stati presentati alla Conferenza Giorgio Rota del 4 maggio 2017, tenutasi presso il Campus Einaudi in collaborazione con il Dipartimento di Economia e Statistica "Cognetti de Martiis". L'Introduzione è di Andrea Brandolini, Banca d'Italia.

La sesta edizione del Premio è incentrata sul tema *The Economics of Health and Medical Care*. I paper vincitori sono stati presentati alla Conferenza Giorgio Rota tenutasi il 1° giugno 2018 presso il Campus Einaudi, in collaborazione con il Dipartimento di Economia e Statistica "Cognetti de Martiis". L'Introduzione è di Fabio Pammolli, Politecnico di Milano.

La settima edizione del Premio è incentrata sul tema *Rural Economies, Evolutionary Dynamics and New Paradigms*. I paper vincitori, riportati qui, sono stati presentati alla Conferenza Giorgio Rota il 6 maggio 2019 presso il Campus Einaudi, in collaborazione con il Dipartimento di Economia e Statistica "Cognetti de Martiis". Gli autori sono introdotti da un intervento di Donatella Saccone, docente di Economia politica all'Università di Scienze gastronomiche di Bra.

Digital Transformation: Analysis of Economic Impact and Potential è il titolo dell'ottava edizione del Premio. I paper vincitori sono stati presentati alla Conferenza Giorgio Rota l'11 maggio 2020 che a causa della pandemia da Covid si è tenuta online, in collaborazione con il Dipartimento di Economia e Statistica "Cognetti de Martiis". Gli autori sono stati introdotti alla Conferenza e nel volume da un intervento di Pietro Terna, ex Professore ordinario di Economia dell'Università di Torino e consigliere Centro Einaudi.

La nona edizione del Premio è stata sul tema *Main Economic Tendencies in the Contemporary World Economy*. I paper sono stati presentati il 26 maggio 2021 alla Conferenza Giorgio Rota che si è ancora tenuta per via telematica. Gli autori sono introdotti nel volume da un con tributo di Jack Birner, Università di Trento e Comitato scientifico del Centro Einaudi.

La decima edizione del Premio aveva per titolo *Labor, value, robots*. I paper vincitori, durante la conferenza tenutasi il 18 maggio 2022 al Campus Luigi Einaudi, sono stati presentati da Elisabetta Ottoz – direttrice del Dipartimento di Economia e Statistica "Cognetti de Martiis" dell'Università di Torino – che introduce anche questo volume.

Urban Economies as Complex Systems è il titolo dell'undicesima edizione del Premio, i cui vincitori – Luca Favero, Ilaria Malisan, Giacomo Rosso e Léa Bou Sleiman – sono stati premiati in occasione della XI Giorgio Rota Conference il 30 maggio 2023 al Campus Luigi Einaudi. Il volume che raccoglie i saggi vincitori è introdotto da Francesca Silvia Rota dell'Università di Torino IRCrES CNR.

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The «Giorgio Rota» Award

The intent of the «Giorgio Rota» Best Paper Award *is to resume the research activity annually conducted by the Giorgio Rota Committee/Foundation before its inclusion in the Centro Einaudi. The focus is on the relationship between economic thought and action and a different aspect of living in society, keeping alive the memory and teaching of economist Giorgio Rota, one of the early members of the Centro, who died prematurely.*

Since 2012, the Centro Einaudi has therefore taken up this legacy by renewing the research formula: this annual prize dedicated to young researchers with an academic qualification in the fields of economics, sociology, geography, political science or other social sciences has therefore been established. Papers may be submitted either in Italian or English, and must not have been published before the date of the Rota Conference, the public event at which the winners have the opportunity to present their work.

The first edition's theme was Contemporary Economics and the Ethical Imperative *and the Giorgio Rota Conference was held at the Centro Einaudi on 25 March 2013 with keynote speech by Alberto Petrucci, LUISS Guido Carli, Rome.*

The second edition, was on Creative Entrepreneurship and New Media *with Conference Giorgio Rota at Centro Einaudi, 14 April 2014 and keynote speech by Mario Deaglio, University of Turin.*

The third edition analysed the topic The Economics of Illegal Activities and Corruption, *with Giorgio Rota Conference at Centro Einaudi, 15 June 2015. Keynote speech by Friedrich Schneider, Johannes Kepler University (Linz, Austria).*

The fourth edition focused on The Economics of Migration. *The Giorgio Rota Conference was held on 20 June 2016 at the Einaudi Campus, in cooperation with FIERI. Keynote speech by Alessandra Venturini, University of Turin. Since 2016, the Prize has also been supported by the Fondazione CRT.*

The fifth edition dealt with Economic Consequences of Inequality, *and the winning essays were presented at the Giorgio Rota Conference on 4 May 2017, held at the Einaudi Campus in collaboration with the Department of Economics and Statistics 'Cognetti de Martiis'. Introduction by Andrea Brandolini, Bank of Italy.*

The sixth edition of the Prize, held in 2018, focused on the theme: The Economics of Health and Medical Care. *The winning papers were presented at the Giorgio Rota Conference held on 1 June 2018 at the Einaudi Campus, in collaboration with the "Cognetti de Martiis" Department of Economics and Statistics. Introduction by Fabio Pammolli, Politecnico di Milano.*

The seventh edition of the Prize focuses on the theme Rural Economies, Evolutionary Dynamics and New Paradigms. *The winning papers were presented at the Giorgio Rota Conference on 6 May 2019 at the Einaudi Campus, in collaboration with the "Cognetti de Martiis" Department of Economics and Statistics. Introductory talk by Donatella Saccone, Professor of Political Economy at the University of Gastronomic Sciences in Bra.*

Digital Transformation: Analysis of Economic Impact and Potential *is the title of the eighth edition of the Award. The winning papers were presented at the Giorgio Rota Conference on 11 May 2020, which was held online due to the Covid pandemic, in collaboration with the 'Cognetti de Martiis' Department of Economics and Statistics. The authors were introduced at the conference and in the volume by a speech by Pietro Terna, former Professor of Economics at the University of Turin and Centro Einaudi advisor.*

The ninth edition of the Award was on the theme Main Economic Tendencies in the Contemporary World Economy. *The papers were presented on 26 May 2021 at the Giorgio Rota Conference online. The authors are introduced in the volume by a contribution by Jack Birner, University of Trento and Centro Einaudi Scientific Committee.*

The tenth edition of the Prize was entitled Labor, value, robots. *The winning papers, during the conference held on 18 May 2022 at the Einaudi Campus, were presented by Elisabetta Ottoz - Director of the Department of Economics and Statistics 'Cognetti de Martiis' at the University of Turin - who also introduced this volume.*

Urban Economies as Complex Systems *is the title of the eleventh edition of the Giorgio Rota Prize, whose winners – Luca Favero, Ilaria Malisan, Giacomo Rosso and Léa Bou Sleiman – were awarded at the XI Giorgio Rota Conference on 30 May 2023 at the Luigi Einaudi Campus. The volume collecting the winning essays is introduced by Francesca Silvia Rota of the University of Turin and IRCrES CNR.*

Chi era Giorgio Rota

Giorgio Rota (1943-1984) è stato professore di Economia politica presso l'Università di Torino e consulente economico. Per il Centro Einaudi, è stato coordinatore agli studi e membro del comitato di direzione di «Biblioteca della libertà».
Le sue pubblicazioni scientifiche abbracciano diversi temi: l'economia dei beni di consumo durevoli, l'economia del risparmio, il mercato monetario e finanziario, l'inflazione e la variazione dei prezzi relativi, il debito pubblico. Ricordiamo tra esse: *Struttura ed evoluzione dei flussi finanziari in Italia: 1964-73* (Torino, Editoriale Valentino, 1975); *L'inflazione in Italia 1952/1974* (Torino, Editoriale Valentino, 1975); nei «Quaderni di Biblioteca della libertà», *Passato e futuro dell'inflazione in Italia* (1976) e *Inflazione per chi?* (1978); *Che cosa si produce come e per chi. Manuale italiano di microeconomia*, con Onorato Castellino, Elsa Fornero, Mario Monti, Sergio Ricossa (Torino, Giappichelli, 1978; seconda edizione 1983); *Investimenti produttivi e risparmio delle famiglie* (Milano, Il Sole 24 Ore, 1983); *Obiettivi keynesiani e spesa pubblica non keynesiana* (Torino, 1983).

Tra le sue ricerche va particolarmente citato il primo *Rapporto sul risparmio e sui risparmiatori in Italia* (1982), risultato di un'indagine sul campo condotta da BNL-Doxa-Centro Einaudi, le cui conclusioni riscossero notevole attenzione da parte degli organi di stampa. Da allora il *Rapporto sul risparmio,* ora *Indagine sul risparmio*, continua a essere pubblicato ogni anno.

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Giorgio Rota's Profile

GIORGIO ROTA (1943-1984) was a professor of Political Economy at the University of Turin and an economic consultant. For the Centro Einaudi, he was coordinator of the Study Committee and member of the editorial board of "Biblioteca della libertà".

His scientific publications cover various topics: the economics of consumer durables, the economics of savings, the money market and the financial market, inflation and public debt. Among his publications: Struttura ed evoluzione dei flussi finanziari in Italia: 1964-73 *(Turin, Editoriale Valentino, 1975);* L'inflazione in Italia 1952/1974 *(Turin, Editoriale Valentino, 1975); in "Quaderni di Biblioteca della libertà":* Passato e futuro dell'inflazione in Italia *(1976) and* Inflazione per chi? *(1978);* Che cosa si produce come e per chi. Italian Handbook of Microeconomics*, with Onorato Castellino, Elsa Fornero, Mario Monti, Sergio Ricossa (Turin, Giappichelli, 1978; second edition 1983);* Productive Investments and Household Savings *(Milan, Il Sole 24 Ore, 1983);* Keynesian Objectives and Non-Keynesian Public Expenditure *(Turin, 1983).*

Particular mention must be made of the first Report on Savings and Savers in Italy *(1982), the result of a field survey conducted by BNL-Doxa-Centro Einaudi, whose conclusions received considerable attention from the press. Since then, the* Savings Report*, now* Report on the Italians' Savings and Financial Choices*, has continued to be published every year.*

Francesca Silvia Rota
Cities as Complex Systems. A Planning Perspective

I am really thankful to Centro Einaudi, Fondazione CRT, and the Departments of Economics of the University of Turin, Cognetti De Martiis and ESOMAS, for giving the opportunity to this speech.

Several years had passed since the first edition of the award was established in 2012 to honour the memory of my father, Giorgio Rota, who was Professor of Political Economy at the University of Turin and a leading Economist at the Centro Einaudi.

It has been a long path to get to this 11th Edition of the Giorgio Rota Conference. Up to nowadays, 33 young emerging scholars from prestigious Universities and research institutes in Italy (Torino, Milano, Firenze, Roma, L'Aquila, Cagliari), Spain (Madrid, Barcellona), Portugal (Lisbona), United Kingdom (York, Bristol, Manchester), France (Paris, Toulouse, Clermont-Ferrand), Belgium (Ghent), Germany (Bonn, Friedrichshafen) and Austria (Linz) have already been awarded (see Table 1) and their contributions are all published in the "Quaderni of the Giorgio Rota Award" series, available for posterity.

To give a flavour of this relevant scientific production on different aspects of the contemporary economy, Table 1 shows the list of the papers awarded in the different editions of the award.

TABLE 1 • EDITIONS, THEMES, AND WINNERS OF THE FIRST 11 EDITIONS OF THE GIORGIO ROTA AWARD

Ed.	*Theme*	*Awarded Papers*
11th	Urban Economies as Complex Systems	Léa Bou Sleiman, *Displacing Congestion: Evidence from Paris* Ilaria Malisan, *The effect of being a European Capital of Culture: Evidence from Matera* (co-author Luca Favero) Giacomo Rosso, *Local Economy Housing Prices and Neighborhood Change*
10th	Labor, Value, Robots	Filippo Passerini, *Monopsony in Labor Markets: Empirical Evidence from Italian Firm* Ana Sofia Pessoa, *Earnings Dynamics in Germany* Eleonora Priori, *Simulating a basic income to cope with the technological transition: an agent-based model*
9th	Main Economic Tendencies in the Contemporary World Economy	Martina Aronica, Caterina Sciortino & Pietro Pizzuto, *Covid-19 and tourism: what can we learn from the past?* Pietro Bompressi & Filippo Passerini, *Directionality of spillovers in Europe: Evidence from the EU sovereign debt Crisis* Luca Sandrini, *Direct and indirect effects of competition on privates incentives to R&D and licensing*

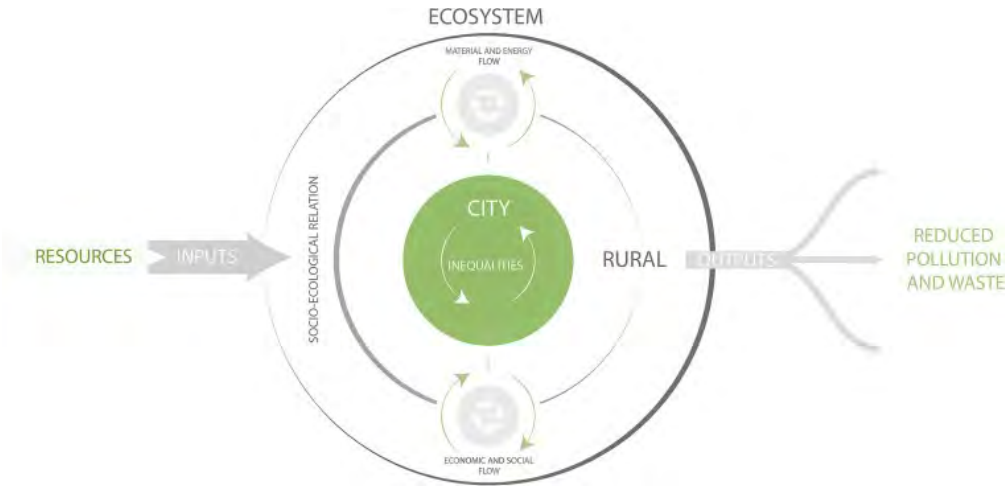
8th	Digital Transformation: Analysis of Economic Impact and Potential	Leonardo Madio, *User-generated Content, Strategic Moderation, and Advertising* Antonio Aloisi, *Hierarchies without firms? Vertical disintegration, personal outsourcing and the nature of the platform.* Moreno Frau, *Digital Transformation behaviors in the agri-food context: an exploratory analysis*
7th	Rural Economies, Evolutionary Dynamics and New Paradigms	Federico Fantechi, *Spatial dynamics of community disaster resilience in rural areas. Evidence from Central Italy after the 1997 earthquake*; Georgios Manalis, *Land rights and risk-sharing in rural West Africa*; Stefano Menegat, Montreal: *Alternative Food Networks: Growing Niches or Paradigm Shift? Exploring the Case of U.S. Farmers' Markets Through a System Dynamics Approach*
6th	The Economics of Health and Medical Care	Gabriel A. Facchini Palma, *Low Staffing in the Maternity Ward: Keep Calm and Call the Surgeon* Valentina Tonei, *Mother's health after childbirth: does delivery method matter?* Gianni Ghetti, *Model for the Estimation of Societal Costs for Pertussis in Italy*
5th	Economic Consequences of Inequality	Bonk Alica Ida, *Capital account liberalization and inequality. The role of skill levels and financial depth* Kurmangaliyeva Madina, *Criminal Justice and Wealth Inequality. How much freedom can money buy in Russia?* Martínez-Toledano Toledano Clara, Dept. of Economics (Paris France) - *Housing Bubbles, Offshore Assets and Wealth Inequality in Spain (1984-2013)*
4th	The Economics of Migration	Ainhoa Aparicio Fenoll e Zoë Kuehn, *Education Policies and Migration across European Countries* Simone Bertoli e Ilse Ruyssen, *Networks and migrants' intended destination* Xingna Zhang, *Analysis of interprovincial migration and its streams in China from 2000 to 2010 with extended and enhanced gravity models.*
3rd	The Economics of Illegal Activities and Corruption	Riccardo Novaro, *Money laundering in the real estate sector: evidence from the Italian market at a provincial level* Lucia Rizzica, Marco Tonello, *Exposure to media and corruption perceptions* Angela De Martiis, *Shadow Economy, poverty and institutional quality*
2nd	Creative Entrepreneurship and New Media	Fania Valeria Michelucci, *New media, financial resources and funding opportunities for creative entrepreneurs* Alessandro Gandini, *Social media e lavoro autonomo. Precarietà, lavoro gratuito, innovazione* Giovanna Santanera, *Afro-modernità in polvere: esperienze*
1st	Contemporary Economics and the Ethical Imperative	Massimiliano Artoni, Matteo Del Popolo, Marco Guerci, *HRM Practices, Ethical Work Climate and Sustainability Perception. An Employee Perspective* Sarah Marie Hall, *Disjointed discourses of Ethical Consumption: Juxtaposing Consumer and Company Narratives* Patrizio Ponti, Federico Tabellini, *Sviluppo umano e sostenibilità ambientale: in cerca di una strada verso l'integrazione*

For the current edition, the aim was to reflect on urban economies as *complex systems*.

Pushed by continued systemic crises and the advent of the industry 4.0 technologies (data analytics, internet of things, cloud computing, additive manufacturing, cyber security, big data, advanced robotics, augmented reality, wearable technology, machine learning, and artificial intelligence), cities are evolving towards hyper-complex multi-layered webs of functions, that pose new challenges and ask for novel paradigms. To say with the philosopher Edgar Morin, we observe a "change of change" that determines a "new complexity of the complexity".

In such a context, scholars from different scientific disciplines argue that theories and methods drawn from *complexity science* are more and more *urgent* to steer the development of cities (Bertuglia and Vaio 2019). Especially after experiencing the covid-19 pandemic, we observe increased general attention to the *liveability* of the urban systems and more frequent use of the metaphor of *urban metabolism* to describe cities as mutually interwoven self-organizing phenomena, evolving like *living systems* (Caldarelli *et al.* 2023).

FIGURE 1 • URBAN METABOLISM CONCEPT. SOURCE: LUCERTINI & MUSCO, 2020: 140



Source: Lucertini and Musco 2020, 140

However, applying to cities the biological analogy also presents some threats.

Firstly, it is sufficient to look back at the history of urban science to realise that the analogy of cities-living organisms arose long ago. To quote Bally and Marshall (2009), "ever since urbanists began to map and describe the city, the language of the human body has been widely used to describe urban form and to suggest ways in which cities might be planned". Examples also are in the works of Leonardo da Vinci, Ebenezer Howard (1898), and Le Corbusier, who considered towns biological phenomena (Le Corbusier 1933; 1947).

Secondly, likening cities to organisms doesn't allow urbanists to cope with the paradox that urban economies are systems *open* in some proprieties yet *closed* in others (Licata 2013) and the fact that cities do not follow a life-cycle developmental programme of birth, growth, maturity, decline, and death.

Thirdly, despite its popularity, the biological analogy has almost often remained implicit in the urban studies and unexploited in its practical consequences: barely anything more than a figure of speech without any direct application (Bally and Marshall 2009).

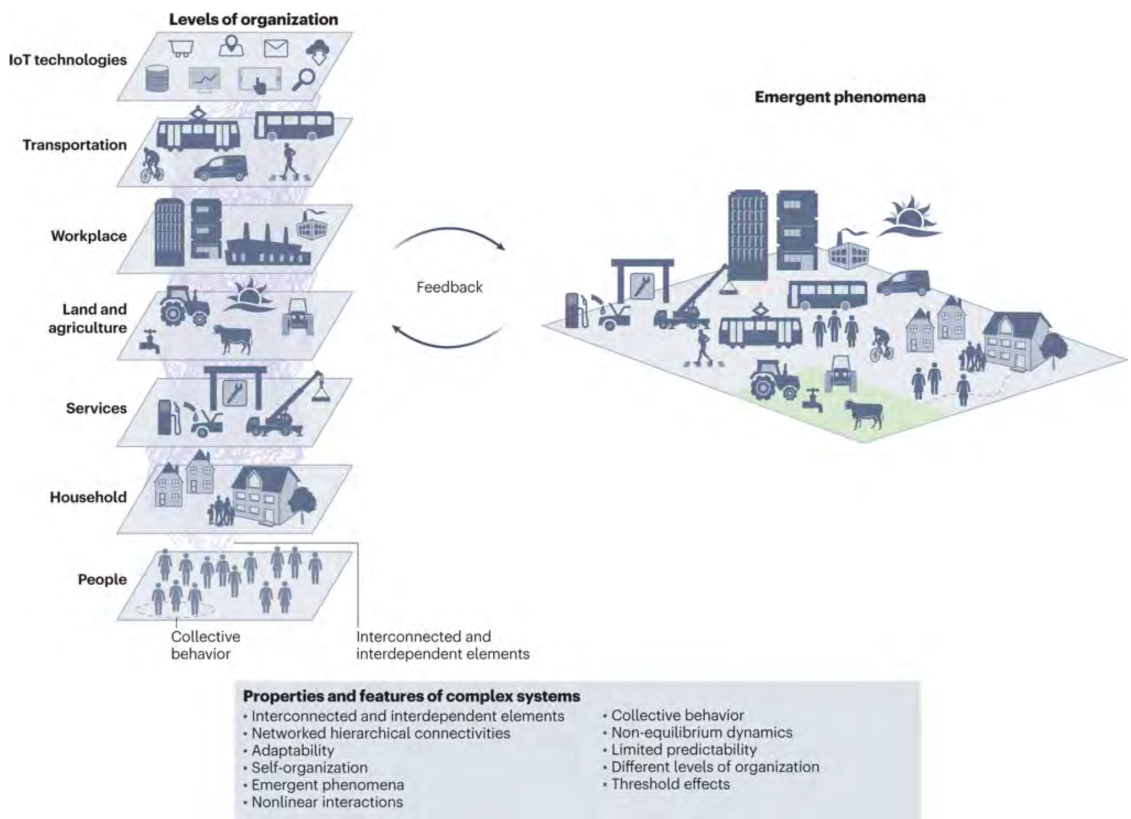
To overcome these limits and give operability to the biological metaphor, complexity science can make a significant contribution.

For instance, it helps planners to identify the role the different actors play at the different levels in the urban system: firms, entrepreneurs, managers, scholars, policymakers, and inhabitants. Figure 2 represents an example of how the city is conceived as a combination of different interacting layers, which gives rise to emergent properties such as clusters of communities and traffic patterns.

Also, it allows scientists to read the dynamics of the city and its interactions from an evolutionary perspective of short- and long-term.

Finally, it explains emerging complex proprieties of the urban economy such as: multi-level interactions and networks, self-organized dynamics, tipping points, and cascading effects.

FIGURE 2 • SCHEMATIC ILLUSTRATION OF A CITY AS A COMPLEX SYSTEM GENERATING EMERGENT PHENOMENA.



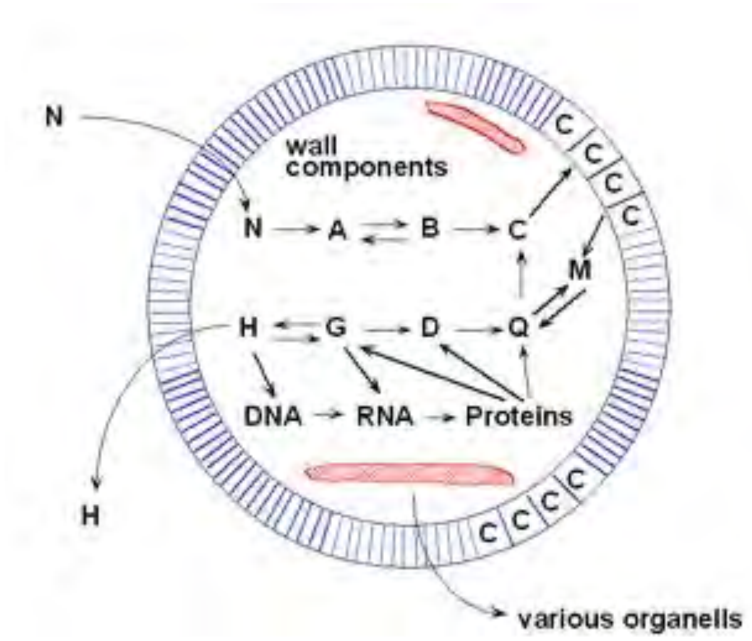
Source: Caldarelli *et al.* 2023, 377

Considering specifically the perspective of urban planning, the recent developments in digital modelling, multi-agent simulation, digital twins of cities, and artificial intelligence are indeed making critical steps ahead in turning operative the analogy of the city as a living system.

The autopoiesis concept elaborated in the 70s by the biologists Humberto Maturana and Francisco Varela, in particular, is at the centre of a new consideration by urban scientists that assumes the form of *a new (planning) autopoietic paradigm*.

Autopoiesis is the property of cells to continuously regenerate and modify their inner processes to react to external influences, preserving structural integrity and the capacity of reproducing (see Figure 3). In the 90s, geographers, as well as planners, urbanists, and political scientists, started using this concept to describe some of the complex dynamics of cities (Dunsire 1996). Similarly to the functioning of the cell as an autopoietic machine (Maturana and Varela 1980), the city too continuously regenerates and modifies its inner mechanisms and processes to preserve from the external influences its structural integrity and the capacity of developing.

FIGURE 3 • THE FUNCTIONING OF A CELL



Source: Lusi 2006

Since the 90s, the autopoiesis concept has thus been diffusely used to describe the city as a self-organising, self-regenerating system, whose constituting parts interact with each other and the external environment via a continuous flux of goods and energy. It has also been used to acknowledge that cities, like other complex social systems, behave as unitary and autonomous collective actors (Dematteis 1994) that have an identity, an agency and a will of their own (Kostof 1992).

At the same time, however, the use of the autopoiesis metaphor often remained superficial. Although it undoubtedly had a pivotal role in the justification of the first experiences of participatory urban planning[1], it is in the light of the recent contemporary challenges of pandemics, climate change, soil consumption, and urban sprawl that we see the attempt of working exhaustively through the theoretical and operational consequence of the biomorphic metaphor for cities and city planning. And the way this attempt is carried out mainly involves the theories and tools of complexity science.

The features of this emerging autopoietic and complex approach to the conceptualisation of cities can be synthesised as follows:

- the city is conceived of as a collection of interdependent coevolving parts without implying there is a fixed relationship or an optimal mature form;
- the city is the result of an open-ended nonlinear co-evolution with the environment and the policy-making, which is unpredictable in the long term (Bally and Marshall 2009).

From a theoretical point of view, it helps re-interpreting existing experiences of policy making, governance and participatory urban planning (Chettiparamb 2020).

From an operational point of view, it helps reframing – via the Industry 4.0 technologies and a variety of modelling styles and types that have recently emerged – digital models of cities in an increasingly detailed and realistic way, so that they can be used in many practical purposes (Caldarelli *et al.* 2023).

Nevertheless, its application to urban theory and planning also suffers from some weaknesses that Caldarelli *et al.* (2023) ascribes mainly to the scarce availability of: data, computational power for large-scale computer simulations, interpretation of results, and determination of tipping points, as well as problem-solving routines and the fixing of systemic instabilities. Also, the fact that urban actors and stakeholders "interact through emergent phenomena such as social norms, individual emotions and personal history [that generate] a highly nonlinear co-evolution in response to environmental changes and governance inputs or related forms of decision-making" (Caldarelli *et al.* 2023, 379) turns the autopoietic approach hard to implement in a real-life urban context.

A solution can arrive from the *urban bioregion* concept elaborated[2] by the planner and territorial scientist Alberto Magnaghi (Magnaghi 2018; 2020a; Fanfani 2018).

According to Magnaghi (2018), an urban bioregion is a territorial local system constituted by:

- a multitude of settlements organised in a non-hierarchical network of cities that are mutually interconnected with their external rural environment in a specific, synergic, and multifunctional way (see the peri-urban region concept);

[1] Modern community planning developed in the late 19th and early 20th centuries when city governments and urban planners started creating centralized, comprehensive community plans.

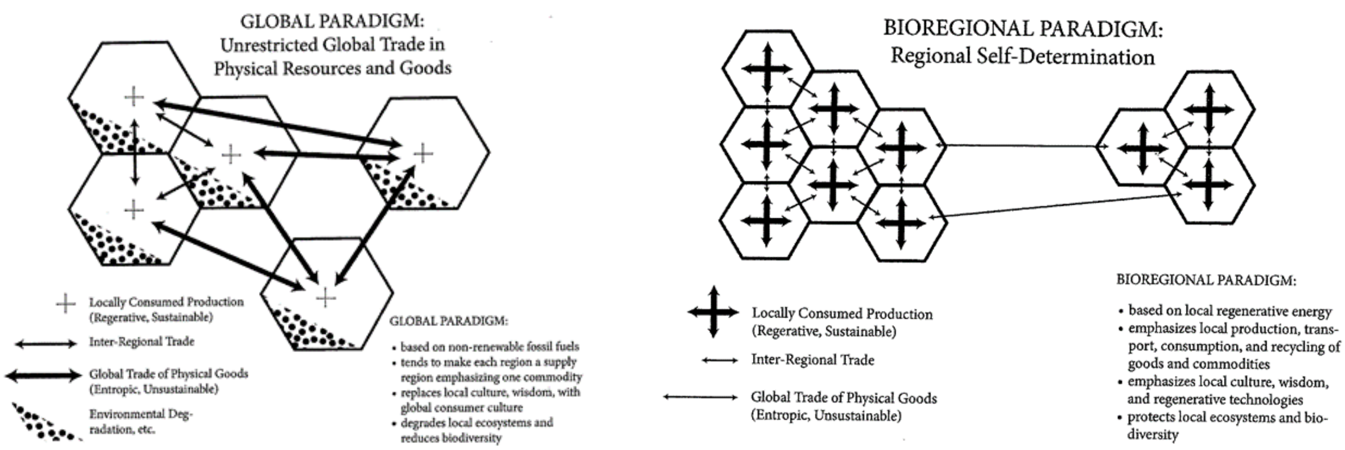
[2] Originally, the idea of an urban biology asking for a bioregional approach emerged in the North America in the 1940s-50s (Bally and Marshall 2009).

- a collection of rural and urban systems embedded in webs of residential, service, and production relationships;
- a diversified system of hydro-geomorphological and natural systems that coevolve with the urban and agroforestry systems;
- a place characterised by specific quality and lifestyle, identity, heritage, long-lasting ecosystem balance and the capability to self-reproduce.

The urban bioregion is a self-governed territorial system whose aim is its own sustainability and the well-being of the inhabitants. To fulfil this aim, the urban bioregion activates local productive systems based on the valorisation of the local capital of common environmental, territorial, social, and cultural goods and the promotion of environmental policies for the closing of the cycles of water, waste, food and energy (Magnaghi 2018).

In the bioregion, each city or cluster of small-medium sized cities coexists with its hinterland in an ecological, productive and social equilibrium that reduces congestion, environmental crises and pollution. In the urban bioregion, the endogenous factors influenced by the external environment are influenced also by their "remote scenario", i.e. by their history and their evolution in time (Bertuglia and Vaio 2019).

FIGURE 4 • RELATIONAL MODELS BETWEEN REGIONS IN LOCAL DEVELOPMENT PROCESSES, ACCORDINGLY WITH BOTH GLOBAL (LEFT) AND BIOREGIONAL (RIGHT) PARADIGMS



Source: Thayer 2013 (quoted in Fanfani 2018, 63)

Magnaghi brings to synthesis the complex system theory and the autopoietic approach to re-frame urban policy-making, governance, and participatory approaches. Consistent with a territorial approach, the urban bioregion assumes the features of a complex living system where the living organisms (humans, plants, animals) co-evolve with their external environment and reproduce in a dynamic autopoietic way (Fanfani and Ruiz 2020, 38).

The strengths of this new planning paradigm are (Caldarelli *et al.* 2023, 379):

- it enhances knowledge (co-)creation, exchange and management at all levels of the government, civil society, the private sector and other relevant stakeholders;
- it increases the capacity to develop and progressively implement urban policies, offering participatory capacity-building processes;
- it provides networking platforms where all the actors of all levels can engage in the development process;
- it considers the endogenous factors influenced by external inputs as well as by their history and evolution.

Also, Magnaghi's urban bioregion provides urban planners and policymakers with:

- a tool to coordinate existing economic plans and strategies such as local communities, energy communities, local productive systems, food systems, green communities
- a tool to experience new solutions of self-efficiency, decarbonisation, and sustainable mobility, production and consumption.

In Magnaghi's view, the solution to the crisis of the contemporary urban model requires the planning of a highly interwoven network of urban villages and local communities (that are also energy communities and green communities) experiencing new solutions of self-efficiency, decarbonisation, sustainable mobility, responsible production, and consumption.

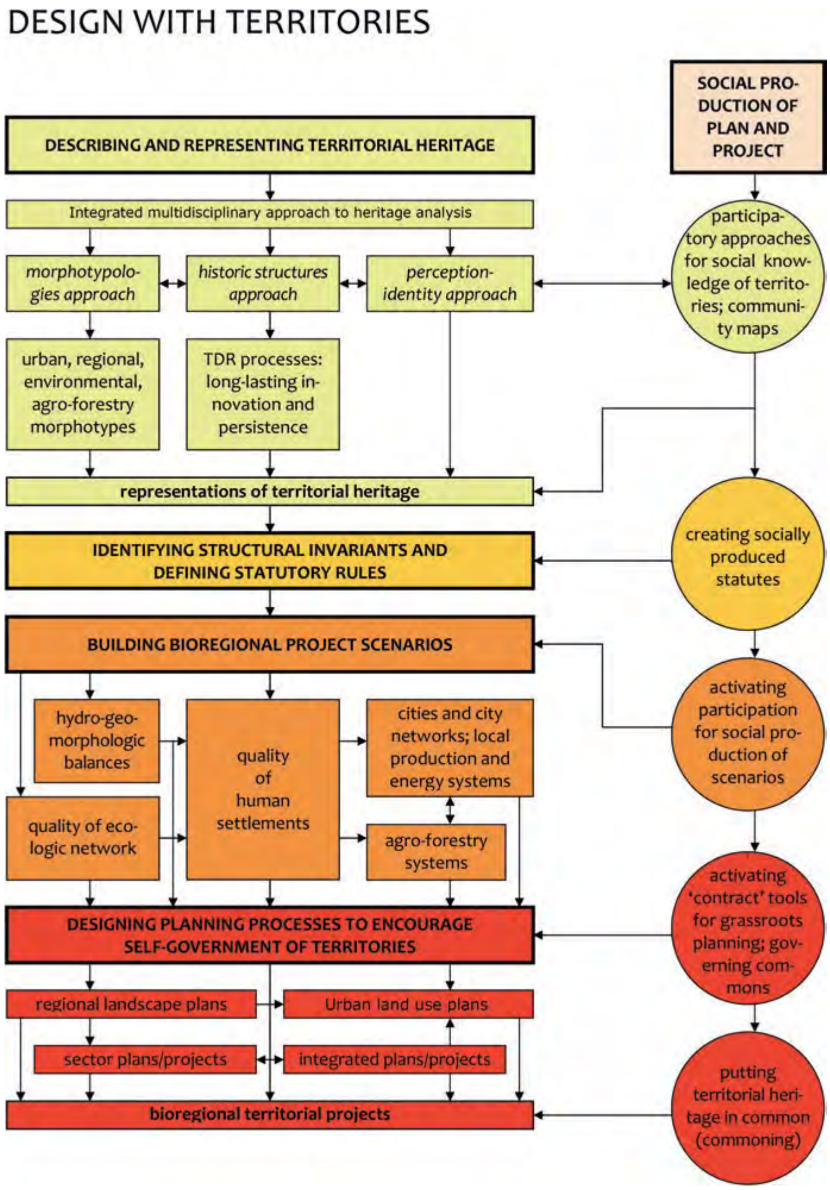
Another strength is the fact that the urban bioregion incorporates also the features of the external urban and non-urban systems as a missing desired value. This "neighbour microcosm" avoids the risk of "a world made of a sum of operatively closed autopoietic systems" that exchange a huge amount of goods, services, money, and information without effective communication and acceptance of their external environment (Dematteis 1996, 42).

The urban bioregion is thus an interpretative tool to critically re-conceptualise the current models of settlement, service and production in a new post-metropolitan perspective. Also, it helps to overcome the existing criticalities of the *metropolis* with practical decisions to:

- re-design the open spaces (agricultural, wooded, fluvial, natural) from a multifunctional perspective and in a framework of self-sustainability;
- complex re-design of the urban-centric networks;
- support urbanity and the urban self-government of the territorial structures and their relationships.

Although the literature on the subject is too young to make final statements, Figure 5 shows that the combination of the autopoiesis concept with the complex system approach appoints Magnaghi's urban bioregion to be a viable design process to combine urban policymaking, governance and participatory approaches, as well as to empower citizens and stakeholders.

FIGURE 5 • DIAGRAM OF THE BIOREGIONAL DESIGN PROCESS



Source: Magnaghi 2020b, 43

In Italy, attempts to apply the urban bioregion are multiplying and involve, up to nowadays, the pivotal cases of Cagliari (Colavitti and Serra 2022), Firenze (Fanfani 2018; Fanfani and Duží 2019), Genova (Lombardini 2022), Torino (Ferlaino and Rota 2022), and Salerno (Panepinto 2022). The case of Torino, particularly, is emblematic of the opportunities linked to the urban bioregional approach. The city, in fact, has an urgent need for a new post-Fordist development paradigm to recover centrality in Europe and it hosts (in the so-called Corona

Verde; Figure 6) a large periurban concentration of productive green and rural spaces, which is ideal for testing the urban bioregional paradigm (Ferlaino and Rota 2020).

FIGURE 6 • LOGO AND AREA OF THE CORONA VERDE PROJECT

Source: http://www.coronaverde.it

In conclusion, we can say that the paradigm of the urban bioregion could unleash new promising paths of urban and territorial planning (Ferlaino and Rota 2022), especially in cities that are suffering from a long period of institutional immobility and closeness (as in the case of Torino). Particularly, this happens because it helps the reduction of soil consumption and urban sprawl, a new alliance with the natural environment, the reduction of metropolitan urban centrism, and the promotion of large-scale polycentrism, self-government, environmental connectivity, and accessibility.

References

Bally M., Marshall S. (2009), *Centenary Paper: The Evolution of Cities: Geddes, Abercrombie and the New Physicalism*, «The Town Planning Review», 80, 6, pp. 551-574

Bertuglia C.S., Vaio F. (2019), *Il fenomeno urbano e la complessità: Concezioni sociologiche, antropologiche ed economiche di un sistema complesso territoriale*, Torino, Bollati Boringhieri

Caldarelli G. (2023), *The Role of Complexity for Digital Twins of Cities*, «Nature Computational Science», 3, pp. 374-381

Chettiparamb A. (2020), *Autopoietic Interaction Systems: Micro-dynamics of Participation and its Limits*, «International Planning Studies», 25, 4, pp. 427-440

Colavitti A.M., Serra S. (eds) (2022), *Building the Urban Bioregion Governance Scenarios for Urban and Territorial Planning*, Firenze, SdT edizioni

Dematteis G. (1994), *Global Networks, Local Cities*, «Flux», 15, pp. 17-23

– (2016), *Geografia come immaginazione. Tra piacere della scoperta e ricerca di futuri possibili*, Roma, Donzelli

Dunsire A. (1996), *Tipping the Balance: Autopoiesis and Governance*, «Administration and Society», 28, 3, pp. 299-334

Fanfani D. (2018), *The Urban Bioregion as Form and Project of the Co-evolution between Urban and Rural Domain. The Case of the Florence Metropolitan Area*, «International Journal of Engineering & Technology», 7, 1.4, pp. 61

Fanfani D., Duží B. (2019), *Urban Bioregion Concept: From Theoretical Roots to Development of an Operational Framework in the European Context*. Atti della XXI Conferenza Nazionale SIU "Confini, movimenti, luoghi. Politiche e progetti per città e territori in transizione", Firenze, 6-8 giugno 2018

Fanfani D., Ruiz A.M. (eds) (2020), *Bioregional Planning and Design: Volume I. Perspectives on a Transitional Century*, Cham, Springer

Ferlaino F., Rota F.S. (2022), *From Industrial Growth Pole to Possible Urban Bioregion: Corona Verde and the New Wave of Urban Planning in Turin*, «Scienze Del Territorio», 10, 2

Howard E. (1904, 2003), *Tomorrow: A Peaceful Path to Real Reform* (original edition with Commentary by Peter Hall, Dennis Hardy and Colin Ward), London, Routledge

Le Corbusier (1933, 1964), *The Radiant City*, London, Faber and Faber

– (1947), *Concerning Town Planning*, London, The Architectural

Licata I. (2013), *Sistemi, Modelli, Organizzazioni. Management e Complessità*, Messina, Corisco

Lombardini G. (2022), *Bioregion as a Knowledge and Project Tool for Metropolitan Territories. Genoa: The Case of Polcevera Valley*, «Scienze Del Territorio», 10, 2

Lucertini G., Musco F. (2020), *Circular Urban Metabolism Framework*, «One Earth», 2, 2, pp. 138-142

Lusi P.L. (2006), *Autopoiesi e definizione del vivente. Una panoramica sull' autopoiesi biologica e la sua relazione con la cognizione*, Bologna, Centro Studi Asia

Magnaghi A. (2018), *La bioregione urbana nell'approccio territorialista*, «Contesti città territori progetti», 1, pp. 26-51

Magnaghi A. (2020a), *Il principio territoriale*, Torino, Bollati Boringhieri

– (2020b), *The Territorialist Approach to Urban Bioregions*, in D. Fanfani, A.M. Ruiz (eds), *Bioregional Planning and Design: Volume I. Perspectives on a Transitional Century*, Cham, Springer, pp. 33-62

Maturana H., Varela F. (1980), *Autopoiesis and Cognition. The Realization of the Living*, Dordrecht, Reidel (trad. it. *Autopoiesi e cognizione*, Padova, Marsilio, 1985)

Panepinto G. (2022), *Place Consciousness as a Method. Reterritorialisation Processes and Governance Practices in the Case of the Vassallo Administration in Pollica*, «Scienze del Territorio», 10, 2

Luca Favero, Ilaria Malisan

The Effect of Being a European Capital of Culture: Evidence from Matera[1]

Abstract. Tourism is an important, cross-cutting source of income and employment. As a potential tool for development, several governmental and intergovernmental initiatives have been put into place to foster tourism. We study the causal link between a mega cultural event, tourism and economic development exploiting the exogenous variation arising from the shortlisting, and subsequent nomination, to the 2019 European Capital of Culture. The title was awarded to Matera, a culturally-rich yet poorly connected and off-beat town in Southern Italy. By means of event study regressions and permutation tests, we compare changes in Matera to changes in other Italian cities unaffected by the policy. We find a boost in touristic presence, which then translates into a decrease in unemployment, an increase in income, firms and workers in industrial sectors even loosely connected with tourism and a remarkable hike in the real estate market. By analyzing the timing of these impacts, we find evidence of a spotlight effect: Matera starts benefiting from the event since the selection phase, even before being awarded the title, possibly due to increased media exposure. All in all, our findings suggest that the European Capital of Culture event could be a viable way for culturally endowed yet underrated destinations to showcase their attractions, in addition to a credible road to development.

Keywords. Tourism, urban economics, economic development, policy evaluation

1. Introduction

Tourism is an important and dynamic source of employment in today's global economy, supporting around 10% of all jobs and accounting for one out of four new jobs created worldwide.[2] Reliance on tourism has also been hailed by many policymakers as a forward option to boost economic activity (Department for culture, media and sport, UK government, 2011) especially in outlying and outermost regions and those lagging behind in terms of economic opportunities (European Commission, 2010). Across the EU, the European Capital of Culture (ECoC) is the most famous example of a cultural policy designed to showcase and raise the in-

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[2] 2019 figures by the World Travel & Tourism Council.

ternational cultural profile of host cities (European Parliament and European Council, 2014). At the same time, host cities can also seize the opportunity to regenerate themselves and boost their socioeconomic development. Set up in 1985, the European Capital of Culture has grown in popularity and it is now regarded as one of the most ambitious and appreciated cultural initiatives of the EU, with a new schedule financed up to 2033 (European Parliament and European Council, 2014). The policy is so established that it has been mirrored by similar initiatives across the world including the City of Culture in the UK, the Italian Capital of Culture, the French Capital of Culture, the Arab Capital of Culture and the American Capital of Culture. This paper aims at providing evidence of a causal link between a mega cultural event, tourism and economic development by exploiting exogenous variation arising from the shortlisting, and subsequent nomination, to the 2019 European Capital of Culture for Matera, Italy. The paper proceeds by investigating how economic development maps out across several dimensions of the hosting city's economy, from income and labour market to the real estate sector. We believe our setting to be particularly appropriate to answer the questions above. This is because of the nature of both the European Capital of Culture, a massive international cultural festival lasting for one year, and of its host city Matera, a small historical town located in Southern Italy, relatively unknown to tourists yet endowed with a formidable cultural potential awaiting to be unlocked.

While Italy has long been a top destination for tourists, consistently ranking in the top five destinations by international tourism arrivals and in the top ten by earnings from tourism (International Tourism Highlights, 2019 Edition 2019), touristic flows are not equally shared within the country. Matera was indeed largely off the beaten tracks, possibly due to a combination of being poorly connected and subpromoted. The ECoC nomination can therefore be seen as both a significant boost in visibility and an enormous chance for regeneration.

In our analysis, we use event study regressions to compare changes in Matera to changes in other Italian cities unaffected by the policy. Importantly, our specification will enable us to provide both evidence of parallel trends, which is key for identification, as well as to show how treatment effects evolve over time from shortlisting to the event year. This result becomes particularly relevant once keeping in mind that Matera was shortlisted in 2013, awarded the title in 2014 but most cultural events only started in 2019. Our estimates provide evidence of a touristic (re) discovery of Matera, that would have likely continued after the event year had it not been for the Covid-19 pandemic. These results mainly speak to the enormous media attention the city has experienced, which we refer to as the "spotlight effect" throughout the paper, rather than budget expenditure, as we discuss in Section 2.2. To overcome hurdles in claiming statistical significance when the number of treated clusters is low, we draw inference from permutation tests following Buchmueller *et al.* (2011), that is by assigning treatment to each unit in the control group and comparing estimates to the results for Matera.

We leverage on several datasets from different data providers. We start by collecting data on touristic flows, population and labour market indicators, including the number of workers and firms by economic sector, from the Italian National Statistical Institute for Italian provinces in the period 2008 to 2019. We then retrieve city level data on personal income declared for tax purpose from the

Italian Ministry of Economy and Finance. Finally, we obtain information on the housing market, where we observe the number of transactions, at the city level, and prices, at a fine neighbourhood level within each city, from the dedicated statistical body of the Italian Revenues Agency.

Our baseline estimates provide evidence of a strong increase in tourism flows and economic development across several channels. We first document a remarkable rise in the number of tourists checking-in in Matera in 2019, +115%, and of the number of nights they spent there, +52%. Importantly, the sustained increase, building up from shortlisting to the event year, is compatible with a spotlight effect deriving from the media exposure Matera enjoyed. We then show how the touristic expansion reverberated in the local economy with an increase of +9.7% for income declared for tax purposes. These results resonate with the marked decrease we find for the unemployment rate, -7.74 percentage points in 2019. We analyze labour market effects in more details by looking at the number of firms and workers by economic sector (ATECO codes). Our results indicate a strong increase in the number of firms and workers operating in the hospitality sector, with +193% firms in holiday and short term accommodations and +55% workers in hotels. Likewise we document an increase in the number of employees in the cultural sector (+277%) and in the infrastructure-related sector (+49% workers in demolition and +43% in architecture and engineering firms).

These findings are consistent with the cultural nature of the policy and the urban and infrastructural regeneration that came with it. Also related with the latter, we find evidence of a 30% increase in the number of firms involved in real estate trading in 2015. This result matches the increase in the number of real estate transactions we find around the same period, +77%. Finally, we investigate how these effects translate into prices for the housing market. Our estimates point to an increase of +12% in prices when looking across areas and buildings in Matera. These effects are driven by strong increases for housing, +43%, and retail units, +30%, in the historical centre of Matera, consistently with a tourism-led growth. All in all, we find the European Capital of Culture initiative to be a successful tool in positioning Matera and its cultural endowment at the touristic forefront in the region, as well as a credible road to development, placing Matera on the map and all the way up to being chosen as the 2021 host of the G20 Foreign Affairs Ministers' Meeting.

We present several robustness checks to validate our results. Across our event study regressions, identification is contingent on parallel trends between treated and control units in potential outcomes. Although in most models small and statistical insignificant lead effects help in providing evidence of parallel trends, we report estimates from alternative specifications where we relax this assumption, as we discuss in Section 6.

This paper relates to studies across several strands of the literature. We add evidence to the academic debate discussing the positive effects of tourism in fostering the economic development of destinations. Starting from Balaguer and Cantavella-Jorda (2002) for Spain, several papers have tested and confirmed the tourism-led growth hypothesis (Dritsakis (2004) for Greece and Gunduz and Hatemi-J (2005) for Turkey). More recently, Faber and Gaubert (2019) exploit differences in beach quality across Mexico to provide evidence of an effect of tourism on economic development, both at the local and at the national level. On this issue, the closest paper to ours is Nocito *et al.* (2021) who look at the effect of entertainment media exposure for a set of Sicilian municipalities and show an increase in tourism activities from foreigners (+300%), which is then linked to taxable income (+4.7% for a 10% increase in tourists' expenditure) and employment in the hospitality sector (+10.1% for a 10% increase in tourists' expenditure). We complement the papers above by analyzing the effect of a massive cultural intervention, large parts of which will also work through enhanced media exposure, on a previously not so touristic city in Italy. Our estimates show an increase in tourism (+115%) from both foreigners and natives, a reduction in the local unemployment rate (-7.74 pp), which is mapped out across economic sectors, as well as an effect on the housing market of Matera.

Our estimates also speak directly to papers evaluating the impact of mega events such as the Olympics Games (Baade and Matheson (2016), Billings and Holladay (2012), Rose and Spiegel (2011), Maennig and Richter (2012) and Firgo (2021)) and to studies explicitly looking at the effect of the European Capital of Culture on hosting cities (Falk and Hagsten (2017), Srakar and Vecco (2017), Steiner *et al.* (2015) and Gomes and Librero-Cano (2018)). Research looking at the economic returns of hosting the Olympics have labelled the event a "money-losing proposition for host cities" (Baade and Matheson 2016) with even some of the long-run positive effects found in previous studies (Rose and Spiegel 2011) not confirmed by papers further refining the control group (Maennig and Richter (2012) and Billings and Holladay (2012)). The main methodological challenge lies in constructing appropriate control groups and collecting fine granular data on economic outcomes over many countries. Firgo (2021), to this end, combines a NUTS1 level analysis, with a careful choice of control group, to report evidence of an increase in relative regional GDP per capita. In this paper, effects start to appear after a planning phase of two years and build up over time. Moreover, effects are only visible for Summer Olympics, all in all suggesting that they derive from the larger boost in investment and private consumption compared to the smaller scale of Winter Games.

Our contribution to this debate is to show the importance of the reputation channel, that we refer to as the spotlight effect, stemming from hosting a cultural and year-long mega event through fine granular data. This is the same channel that has likely played a key effect for the successful touristic development of Barcelona, which hosted the 1992 Summer Olympics and moved on to enjoy a robust touristic growth thereafter (Zimbalist 2020). The event we exploit is however much smaller in scope and has a tiny budget compared to the colossal amounts spent on Summer Olympics.[3] The two events are also sharply in contrast when it comes to the relationship between their entertainment component and the host city. While the entertainment value of the Olympics Games is roughly homogeneous regardless of where they are hosted, the entertainment component of the ECoC is heavily reliant on the host. Finally, while both types of event are likely to trigger investments in the hospitality industry, hosting the Olympics requires heavy investment for a peek period of about two weeks, compared to year-long European Capital of Culture, and is likely to leave the city with over capacity once the event is over.

[3] The city of Chicago alone spent more than the entire operating budget of Matera 2019 for its bidding application to the 2016 title, a process which turned out to be unsuccessful (Baade and Matheson, 2016).

Several papers have commonly reported an increase in tourism following a nomination to host the EcoC (Falk and Hagsten (2017), Srakar and Vecco (2017)). Falk and Hagsten (2017) combine differences in differences with propensity score matching to study the effect on overnight stays on 34 ECoC hosts. They estimate an average increase of 8% or 40,000 nights, which masks highly heterogeneous city-specific estimates. Indeed, according to their study, second-tier cultural cities benefit the most (up to +37% for Weimar, ECoC 1999). Srakar and Vecco (2017) analyze the case of Maribor, Slovenia, ECoC capital in 2012 and find a similar increase in touristic arrivals (+20,000) and overnight stays (+ 50,000). Our estimates are generally higher, likely due to both Matera being similar to the underrated cultural city group in Falk and Hagsten (2017) and to the fact that we compare the event year with the shortlisting year, rather than with the year before the event. Overall, our estimates corroborate findings of positive effects on touristic inflows and show that tourism begins to increase even prior to the event year, around the time when the title is awarded and cities get under the spotlight, providing evidence towards the reputation channel. This latter result is important to explain the magnitude of our results and seems to suggest that previous estimates, which did not take into account the dynamic nature of these effects, might have to be interpreted as a lower bound.

On the other hand, the evidence on economic development and employment remains mixed. Steiner et al. (2015) find no evidence of an effect when it comes to GDP per capita contrasting NUTS2 regions. Gomes and Librero-Cano (2018), instead, show that hosting the ECoC stimulates regional GDP per capita by contrasting NUTS3 regions in a dynamic difference-in-differences set up, but find no evidence of effects when it comes to the labour market. As in Gomes and Librero-Cano (2018), we find evidence of an effect even before the ECoC year. Our estimates on the labour market, however, point towards a 7.74 percentage points reduction in unemployment. As stated in their paper, the lack of effects could be due to measurement error due to the pooling of several host cities; furthermore, by focusing on a single Capital, our estimates are less likely to be affected by any confounders. Similarly, Srakar and Vecco (2017) find a decrease in employed Maribor residents (-3,000). As acknowledged in the paper, this could be due to the effects of the concurrent financial crisis or to issues with the econometric model. We add to the debate above by providing evidence of a clear effect in Matera's labour market and showing how these effects are not only present in the hospitality sector, but they also reverberate through the culture, building and construction sector.

Finally, this paper contributes to a recent stream of the literature linking the effect of tourism on the housing market. A series of papers, see Horn and Merante (2017) for Boston, Koster *et al.* (2021) for Los Angeles, Garcia-López *et al.* (2020) for Barcelona and Peralta *et al.* (2020) for Lisbon, document a sizeable impact of listings on Airbnb, the renowned house sharing platform, on housing prices and rents, with effects stronger (+15%) in the more touristic areas (Koster *et al.*, 2021). While we do not observe data on the number of Airbnb listings, Picascia, Romano and Teobaldi (2017) highlight how the proportion of housing stock in the historical centre of Matera listed on Airbnb as "entire place" grew from 17.30% to a staggering 25.30% between 2015 and 2016. The 2016 value represents the highest figure across Italian cities and suggests that a sizable part of the touristic flows might have lodged in accommodation rented through sharing platforms. Our estimates complement these findings by showing an increase in the number of companies working in the real estate sector in the years 2014 and 2015, plus an increase in the number of real estate transactions shortly after. Furthermore, we document a strong yet comparable increase of around +12% in housing prices, mostly driven by residential and commercial units in the historical centre of Matera.

The remainder of this paper is organized as follows. Section 2 describes Matera and the European Capital of Culture event. Section 3 presents the data we collected and Section 4 outlines the empirical strategy. Section 5 presents the main results, Section 6 discusses robustness checks while Section 7 concludes.

2. Policy context

This section describes Matera and the European Capital of Culture policy. It is key to understand the background of the paper and interpret our results.

2.1 Matera: The City of Stones

Matera is a municipality and province in the Southern Italian region of Basilicata4. The municipality is home to 60,000 inhabitants and heads a province of about 200,000 citizens. Matera is an ancient city, with the first signs of settlements dating back to prehistory (APT Basilicata, 2019). The unique and fascinating landscape of the Sassi (Stones) neighbourhood, made of grottoes carved out of limestone, is a recognized World Heritage Site by UNESCO and strikes a chord with visitors.

Despite its architectural wonders and being today a popular tourist destination, life in Matera, and especially in the Sassi area, has been rough. The sordid living conditions in the Sassi, plagued by poverty, famine and malaria, were first brought to the fore by the 1945 book *Christ Stopped at Eboli* written by Carlo Levi during his exile in Basilicata. In 1948 the leader of the Italian Communist Party, Palmiro Togliatti, labelled the appalling living conditions in the area of the Sassi a "national disgrace" (Catullo, 2020). A 1952 national law started a relocation plan to move out citizens to newly built accommodations in the periphery. Over half of Matera's population at the time, around 16,000 individuals, was affected by the relocation policy (OpenData Matera, 2019). The Sassi were therefore vacated and laid abandoned for years. The situation only started to change in 1986, when a second law was passed to promote investment in the area and which eventually led to people retaking the Sassi, the nomination to a world Heritage site in 1993 and the shooting of Mel Gibson's *The Passion of the Christ* in 2004.

[4] Basilicata hosts two province capitals: Potenza which also serves as capital city of the region and Matera.

Matera's economic hardship however did not fade way. In 2012 Matera's GDP per capita[5] was 17,500, considerably lower than the Italian average of 26,900 euros and slightly lower than the regional value of 19,900 euros. Likewise the unemployment rate[6] was 17.42%, far higher than 10.68% for Italy and 14.55% for Basilicata. At the same time, despite the impressive potential for tourism, Matera hosted 1.5 tourists per inhabitant in 2012; this is way less than 6 and 2.83 for other finalist cities such as Siena and Perugia but more than the neighbouring cities of Bari and Cosenza, which hosted 0.52 and 0.85 tourists per inhabitant respectively.

Life in Matera started to change in 2013, when the city was brought to the spotlight after being shortlisted for the 2019 European Capital of Culture, a title officially won in 2014. The shortlisting, and the eventual awarding of the title, brought an enormous media coverage the likes of which Matera had never experienced before. Around 140 international news outlets (radio, newspapers and TVs) across 42 countries covered Matera, with the city even being ranked third in the top 52 travel places by the NYTimes[7] in 2018. Matera also made it to the big screen with about 30 films being shot in the city and surrounding areas since 2014 (Commission *et al.* 2020). National media exposure was massive as well, with more than 6,500 news articles published between 2019 and March 2020. The 2019 inauguration event broadcast by Rai Uno, the flagship channel of national television[8], reached about 3,883,000 viewers amounting to 20.8% of television share (Matera Basilicata 2019 Foundation, 2021).

2.2 European Capital of Culture

The European Capital of Culture is a EU initiative designed in 1985 by the European Commission (European Commission, 2020b). Its main aim was, and still remains today, to bring EU citizens closer by providing a unique stage to showcase the cultural diversity of the Union, as well as an opportunity to appreciate its common history and values (European Parliament and European Council, 2005). Cities awarded the European Capital of Culture title enjoy a unique occasion to boost their cultural profile worldwide. At the same time, they also grab a chance to regenerate themselves on the longer term, enhancing the prosperity and quality of life of their citizens. Cities awarded the title invest in culture as a road to development expecting returns from the infrastructures they build for the occasion and the touristic inflows.

Since 2005, one or more European Capital of Culture is selected each year among Member States cities. In 2019 Italy and Bulgaria were both asked to recommend one of their cities to host the title. The life-cycle of Matera as a European Capital of Culture[9] begins six

[5] Eurostat, NUTS3 figure.

[6] ISTAT, unemployment rate 15-74 age group NUTS3 figure.

[7] *52 Places to Go in 2018 NYTimes* (2018).

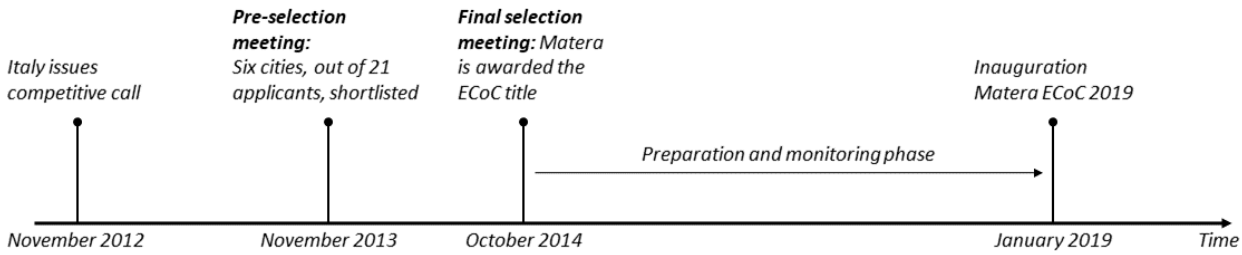
[8] Radiotelevisione italiana, the Italian state-owned television network.

[9] At the time Matera was selected, the selection proceeded according to European Parliament and European Council (2006). However, this has been amended by European Parliament and European Council (2014), currently in effect.

years before the title year, when Italy publishes a call for their cities to bid. During the next two years bidding cities are evaluated by a panel of 13 independent experts, six nominated by Italy and seven by European Institutions (European Parliament and European Council, 2006). A formal nomination of the winning cities takes place four years before the title year. Winning cities remain constantly monitored and advised by the panel and the European Commission while working towards the event year. During the period, local administrations receive both national and European funds and are tasked with urban projects, as well as the organization of the body of cultural events. Overall, the budget for Matera 2019 was composed of 54.8 € million for current expenditure, in addition to the ordinary cultural budget of the city, with 70% of the budget being financed by the Italian central government, 25% by regional and local authorities, and the remaining part by the European Union and private sponsors (European Commission, 2020c). The bidbook for Matera also included an hefty 650 € million budget of capital expenditure with spending items classified as either culture infrastructure, urban revitalization or accessibility infrastructure. Despite the colossal resources, which might cast concerns on what is driving our estimates, we show in Table A.1 in the online Appendix how the proposed Capital of Culture budget and bidbook included project which were already planned in Matera. Indeed, several key infrastructure projects already were either under construction during the bidding period, agreed upon a long time before or, to the best of our knowledge, never implemented. We also retrieved bidbooks for all six 2019 Italian ECoC finalist cities to provide suggestive evidence of how cities populated the budget section of their bidbooks with infrastructure spending already planned, even if unrelated to the European Capital of Culture event. This comparison is also reassuring as it suggests Matera was not unique in large capital expenditure and that similar resources might have been invested in finalist cities or cities in our control groups for which we do not observe bidbooks.

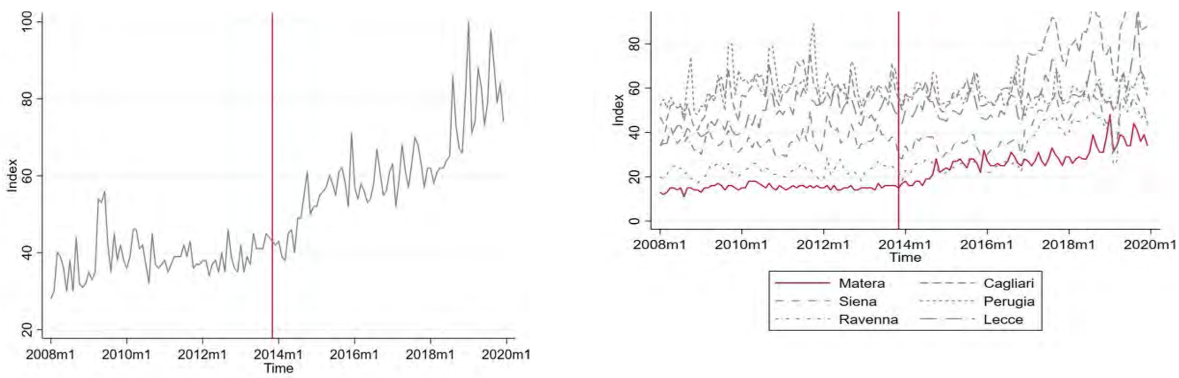
Not surprisingly, the selection process is usually highly competitive and it has been particularly so in the case of the 2019 title in Italy (European Commission, 2020b). Twenty-one candidate cities responded by submitting a bid. The selection panel eventually recommended the Italian government to shortlist six candidate cities to the final selection stage. The six finalists were Cagliari, Lecce, Matera, Perugia, Ravenna, and Siena. The final selection took place during a final meeting, when the panel voted 7 to 6 in favour of Matera. Figure 1 summarizes the key selection steps that led to awarding the title.

FIGURE 1 • SHORTLISTING PROCESS



As Matera was shortlisted in November 2013, gaining immediate national interest, we set 2013 as the year of treatment[10]. Indeed, descriptive evidence shows how tourism and interest in Matera started to increase since the shortlisting date. Likewise, Figure 2a shows how Google searches[11] for Matera began increasing around the end of 2013, with peak interest reached at the inauguration of the event year in early 2019. Moreover, Figure 2b shows how this hike in media attention only applies to Matera and not to other finalist cities, a point on which we return in Section 6. Lastly, the presence of, and interest towards, Matera on social networks boomed during the ECoC competition. Indeed, the day of the shortlisting saw the hashtag supporting Matera's bid as 2019 European Capital of Culture as trend topic on Italian Twitter (Matera 2019 Committee, 2021). Interest in Matera steadily rose and peaked in the European Capital of Culture year, during which more than 1,300 events were implemented, along with two flagship projects, four thematic exhibitions and 40 international meetings. Over 140,000 tickets were sold, while free events reached about 350,000 individuals (European Commission, 2020c).

FIGURE 2 • MEDIA ATTENTION



(a) Google searches for "Matera"

(b) Google searches for finalist cities

[10] This happens in outcomes for which we have yearly data. When higher frequency data are available, we set treatment as close as possible to November 2013, i.e. the second semester or last quarter of 2013.

[11] Data for Google Searches refers to an index peaking at 100 for the most searched term. Values for all other terms are scaled compared to the most search item.

The project which led to Matera 2019 envisioned an engagement of the whole region of Basilicata in the title. Indeed, although Matera has been venue for the majority of the events, about one third of the activities brought to life during the European Capital of Culture year took place in a Basilicata municipality different from Matera, either as supporting venue or as primary location (Matera Basilicata 2019 Foundation, 2021). Hence, our analysis will concentrate on the provincial level, eventually zooming into the city of Matera whenever data allows. For the same reason, we consider the province and city of Potenza, the largest city in the region and host of several events, as partially treated, and thus exclude it from the control group of the main specification.

3. Data

We collect data on touristic flows and accommodations, unemployment rate, resident firms and staff by sector, population, income declared for tax purposes, real estate transactions and average sell price. Our data sources include the Italian Statistical Agency (ISTAT), the Italian Ministry of Economy and Finance (MEF) and OMI (Osservatorio del Mercato Immobiliare), the housing statistics body of the Italian Revenues Agency12. Table 1 describes, for each outcome variable, time span availability, frequency, source and observation level. Overall, we work with an unbalanced panel of 30 provinces (or province capitals) of yearly (or higher frequency, whenever available) data from 2008 until 2019.

We standardize several variables to ease the comparability of the results when performing permutation inference, as discussed in Section 4. We standardize the number of tourists checking in, the number of nights they spent, the number of accommodation facilities, the number of firms and workers for each ATECO 3 digits code13, the number of OMI transactions and income reported for tax purposes by thousand inhabitants of each province in 2009. For the housing market, we work with average sell price by areas, i.e. collection of neighbourhoods equally distant from the city centre, and building category.

Across all data sources, we remove observations for provinces which were created, suppressed or modified during our study period or where there was no single municipality serving as province capital14. The control group in the main specification is made of all provinces (or province capitals, depending on the unit of observation in the data) in Southern Italy, excluding the provinces of Potenza and Lecce. We exclude the former as it was a secondary host for some events during the ECoC year, as we discuss in Section 2.2, and the latter to avoid contaminat-

[12] Agenzia delle Entrate.

[13] ATECO (Classification of Economic Activity) 2007 codes are used to define industry sectors and relative description, as per Italian Statistical Agency's national version of European nomenclature.

[14] We excluded the following provinces: Verbano-Cusio-Ossola, Monza e della Brianza, Pesaro e Urbino, Fermo, Massa-Carrara, Barletta-Andria-Trani and the island of Sardinia.

ing our estimates with spotlight effects on finalist cities15. Figure A.1 in the online Appendix summarizes the geographical coverage of the data and of the control group we use for the main specification. Table A.3 presents descriptive statistics, while Section A.1 in the online Appendix details data structure and cleaning.

TABLE 1 • DATA SOURCES

Variable	*Time span*	*Frequency*	*Sources*	*Observation level*
Touristic flows and accommodations	2008 - 2019	Yearly	ISTAT	NUTS3
Unemployment rate	2008 - 2019	Yearly	ISTAT	NUTS3
Resident firms and staff (by ATECO)	2008 - 2018	Yearly	ISTAT	NUTS3
Population	2008 - 2019	Yearly	ISTAT	NUTS3
Income declared for tax purposes	2008 - 2019	Yearly	MEF	City head of province
Housing transactions	2011 - 2019	Quarterly	OMI	City head of province
Housing prices	2008 - 2019	Biannual	OMI	LAU* and lower**

* Local administrative units, according to the European Union's Nomenclature of Territorial Units for Statistics.
** Area, i.e. collection of neighbourhoods, and building category.

4. Identification strategy

This paper aims at identifying the impact of hosting the European Capital of Culture on income, labour and housing market outcomes by exploiting exogenous variation arising from Matera's shortlisting in 2013. We leverage on event study regressions where we compute dynamic treatment effects, one for each year after shortlisting, by contrasting changes in outcomes for Matera over time with changes in control cities. The choice of following an event study framework is particularlyrelevant given that we expect dynamic treatment effects to build up over time until 2019, when the event took place. Our main specification is described in Equation 1 below:

$$Y_{pt} = \beta_0 + \sum_{\substack{\tau=2008 \\ \tau\neq 2012}}^{2019} \beta_\tau MT_{p\tau} + \delta_p + \gamma_t + \epsilon_{pt} \qquad (1)$$

where Ypt is the outcome of interest for province p at time t, $MT_{p\tau}$ is a dummy equal to 1 for Matera in year τ and zero otherwise. We control for province and time fixed effects while ϵ_{pt} is the error term. When analyzing tax data, p is set to indicate province capital city, i.e. the level of observation for these outcomes.

[15] Results remain qualitatively similar when including these provinces as show in Section 6

We slightly modify Equation 1 into Equation 2 to fit higher frequency, quarterly housing transaction data, as in our real estate data. Here the unit of observation is the province capital city c, while we continue to indicate year with t for consistency.

$$Y_{cqt} = \beta_0 + \sum_{\substack{\tau=2011q1 \\ \tau\neq 2013q3}}^{2019q4} \beta_\tau MT_{c\tau} + \delta_c + \gamma_{tq} + \rho_{cqt} \quad (2)$$

where Y_{cqt} is the number of housing transactions in province capital city *c*, in quarter *q* and year *t* and we control for province capital, year by quarter time fixed effects.

Finally, the granularity in the housing market data allows us to leverage on variability across building categories, in different neighbourhoods, across city-by-semester cells. To ensure comparability, we again limit our analysis to towns which host province capitals, such as Matera. First, we run a city-wise analysis of housing market prices, adding detailed city-by-area-by-building-category fixed effects. We then explore heterogeneous effects on progressively finer real estate markets: we look at the area level, i.e. a collection of neighbourhoods equally distant from the city centre, and finally at a set of building categories within an area. In Equation 3, we define each market *m* and control for market fixed effects. This allows us to progressively zoom in when estimating β^m coefficients, with market *m* indicating building category by area within a city, area within a city, then city-wise fixed effects:

$$Y_{mst} = \beta_0 + \sum_{\substack{\tau=2008s1 \\ \tau\neq 2013s1}}^{2019s2} \beta^m_\tau MT_{p\tau} + \delta_m + \gamma_{ts} + \eta_s + \phi_{mst} \quad (3)$$

where δ_m are market fixed effects, and *m* indicates: city-wise *p*, area within a city *pa*, and finally building category within an area pac real estate market. γ_{ts} are year by semester time fixed effects.

Identification is contingent on the parallel trend assumption, according to which, in absence of treatment, outcomes for treated and control units would have evolved along a parallel path. While the assumption cannot be tested, lead treatment effects (β_τ associated with lagged treatment variables) are commonly deployed to provide evidence of similar trends prior the introduction of the policy and hence serve as a falsification test.

We investigate alternative specifications which relax this assumption as a robustness check (Angrist and Pischke, 2008). To do so we estimate a Difference-in-Differences regression (DiD) where we first allow for unit specific time trends and then for linear and quadratic unit specific time trends whenever lead coefficients seem to suggest quadratic pre-trends. In both cases we follow Wolfers (2006) imposing minimal structure on the dynamic treatment effects to avoid confounding coefficients from DiD models with time trends. This amounts to estimating the specifications below, with and without imposing $\delta_{2p} = 0$:

$$Y_{pt} = \beta_0 + \sum_{\tau=2013}^{2019} \beta_\tau MT_{p\tau} + \gamma_t + \delta_{1p}t + \delta_{2p}t^2 + \rho_{pt} \quad (4)$$

We run similar specifications on data with different granularity with estimating equations available in the online Appendix.

The control group for all equations in our main specification is composed of provinces or province capitals, depending on the dataset, in Southern Italy. We exclude Potenza and Lecce as outlined in Section 3. Section 6 shows that our results remain qualitatively similar when dropping neighbouring provinces or when contrasting Matera with provinces from the whole country.

When we turn to significance, Bertrand *et al.* (2004) show how standard errors in DiD models are likely to be underestimated, especially when working with outcomes that are potentially serially correlated, such as labour market indicators. The common solution to the problem is to compute standard errors by using the clustering framework. Nevertheless, the number of treated clusters matters when drawing statistical inference, as shown by MacKinnon and Webb (2017). Drawing inference is notoriously difficult in settings where there is only a few treated clusters, with over rejection rates as high as 80% (MacKinnon and Webb, 2017). Moreover, canonical standard errors might not provide an accurate measure of design-based uncertainty (Abadie *et al.*, 2020). This is the type of uncertainty that we are interested in: we are not working with samples and our main source of uncertainty stems from the fact that we do not observe the counterfactual outcome for the treatment unit. Finally, relying on standard errors, usually derived from large sample properties where the number of units approaches infinity, might be even more inappropriate in this paper as we focus on a single treatment unit (Cunningham, 2021).

For this reason we follow Buchmueller *et al.* (2011) in drawing inference from permutation tests where we drop Matera, reassign treatment to each unit in the control group and compute a distribution of placebo treatment effects. We then augment this distribution with effects found for Matera and compute exact p-values (Heß, 2017). We apply permutation tests across all specifications. An alternative identification strategy would leverage on Synthetic Control Method (Abadie and Gardeazabal, 2003). This methodology would however require even longer time series that might be difficult to collate or of limited comparability because of breaks due to changes in definitions affecting relevant variables in our setting.

5. Results

In this section we present and discuss empirical results from our main specification. Our figures combine coefficients for Matera, in red, together with results from permutations, shown in grey, to draw statistical significance. The grey bar for each coefficient reports the range of estimates between the 5th and the 95th percentiles of the placebo distribution. This allows claiming statistical significance, at 10%, whenever the coefficient for Matera lies outside the grey area. We report exact point estimates and p-values computed following Heß (2017) in Tables A.5 and Table A.6 in the online Appendix.

Importantly, our event study specification enables us to track the pattern of effects over time. This is useful both to gauge the presence of parallel trends prior to the event, by looking at coefficients for lead effects, and to assess how impacts evolve over time. The lead coefficients paint a reassuring picture, providing supporting evidence towards parallel trends for most outcomes. Moreover, we examine more into detail the few outcomes for which this is not the case in Section 6. The post-treatment coefficients, on the other hand, are consistent with the idea of Matera being slowly brought into the spotlight and into touristic routes thanks to the shortlisting and nomination as European Capital of Culture.

Figure 3 shows results for our main specification, Equation 1, on the effect of being shortlisted, and subsequently winning, the European Capital of Culture title on our set of outcome variables for tourism. Our estimates point towards a strong and statistically significant increase across all measures of touristic activities since shortlisting in 2013. We show an increase in hotel clients growing over time and peaking at +1,723 check-ins per thousand inhabitants in 2019. Similarly, figure 3b shows an increase in overnight stays, pointing, in 2019, to 3,390 more nights spent in the city per thousand inhabitants. The number of accommodation facilities also increases by 2.76 establishments per thousand inhabitants as in figure 3c. The magnitude of these effects can be appreciated by rescaling coefficients to the population of Matera in 2009 revealing +346,000 check-ins, nearly a 115% increase from the pre-treatment level of 302,000 clients in 2012, +681,000 overall nights, or +52% compared to 1,314,000 in 2012 and +542 facilities versus 299 establishments in 2012.

Remarkably, our estimates also point towards strong effects prior to 2019, when most exhibitions and cultural events had not taken place yet, and can be reconciled with a spotlight effect stemming from the massive media exposure Matera enjoyed since being shortlisted. This result is also suggestive that our effects are not utterly dependant on the cultural initiatives that have taken place in 2019 but could also indicate a robust touristic rediscovery of Matera that is likely to persist to some degree after 2019.

Figure 4 investigates the effect on income declared for tax purposes, expressed in thousand euros per thousand inhabitants in the province. This is found to increase in 2019 with +354 thousands euros per thousand inhabitants or +71,116 thousands euros, revealing an increase of +9.7% compared to the pre- treatment values of 734,308 thousands euros in 2012. Figure 4 also plots impacts on the labour market, revealing a deep reduction in the unemployment rate which seem to be stronger for men. In particular, our estimates provide evidence of a drop over time with the largest effect in 2019, corresponding to a reduction of 7.74 percentage points.

We explore these effects in more detail by investigating the number of firms and workers through a fine granular classification (ATECO 3 digits codes) in Figure 5. For each sector, shown on a different panel of Figure 5, we report estimated coefficients for the number of firms (left) and the number of workers (right). Given that cultural events are the backbone of the European Capital of Culture initiative, it is reassuring to find an increase in Matera's cultural sector, both in the number of firms, peaking early on at +0.015 firms per thousands inhabitants, or 3 additional firms (+33%), in 2016 and workers, closer in time to the event and up to +0.25 workers per thousand inhabitants, or 50 individuals in 2019 (+277%). Consistently with the evidence on tourism flows, we find an increase in the number of firms and workers in sectors closely related to the hospitality industry. In particular, firms in the hotel and catering sectors peak early on around 2015, with an increase of 0.06 and 0.03 firms per thousand inhabitants, or 12 (29%) and 6 (100%) firms respectively. On the other hand, firms in short-stay accommodation and reservation services, which encompass touristic guides, seem to experience growth closer to the event year, the former showing an increase of 0.49 firms per thousand inhabitants, or 98 (+193%) overall, the latter of 0.11 firms per thousand inhabitants, or 22 firms (+106%) overall. Workforce-wise, we see an increase in the number of workers in hotels (+1.05 per thousands inhabitants, or 210 individuals overall, +55%) and restaurants (+1.68 per thousand inhabitants, or 338 individuals overall, +24%). Overall, we find evidence of a positive effect on sectors related to cultural touristic flows which are likely to be attracted by the European Capital of Culture event.

We find similar evidence for sectors that are likely to have benefited from the boost in infrastructure spending associated with the event as we discuss in Section 2.2, especially on the workforce side. Overall, workers in demolition, construction activities and architectural and engineering activities appear to have increased the most with +0.41, or 82 individuals at its peak in 2017 (+49%), +0.90, or 175 individuals (+106%), and +1.64, or 330 individuals (+43%), respectively in 2019.

The timing of the effects depends on the specific sector, with infrastructure-related industries such as construction, engineering and real estate peaking in the preparatory years (i.e., between shortlisting and the actual event year) while culture, restaurants and short-stay accommodation, more heavily dependent on the event itself, reach their peak closer to 2019. Interestingly, we observe a double peak in sectors related to tourism in a traditional sense: hotels and reservation services (i.e., touristic guides) show a local maximum around 2015, the year after Matera is awarded the title, and then a second increase up to the highest value in the event year. We take this as supporting evidence towards the spotlight effect we outlined above.

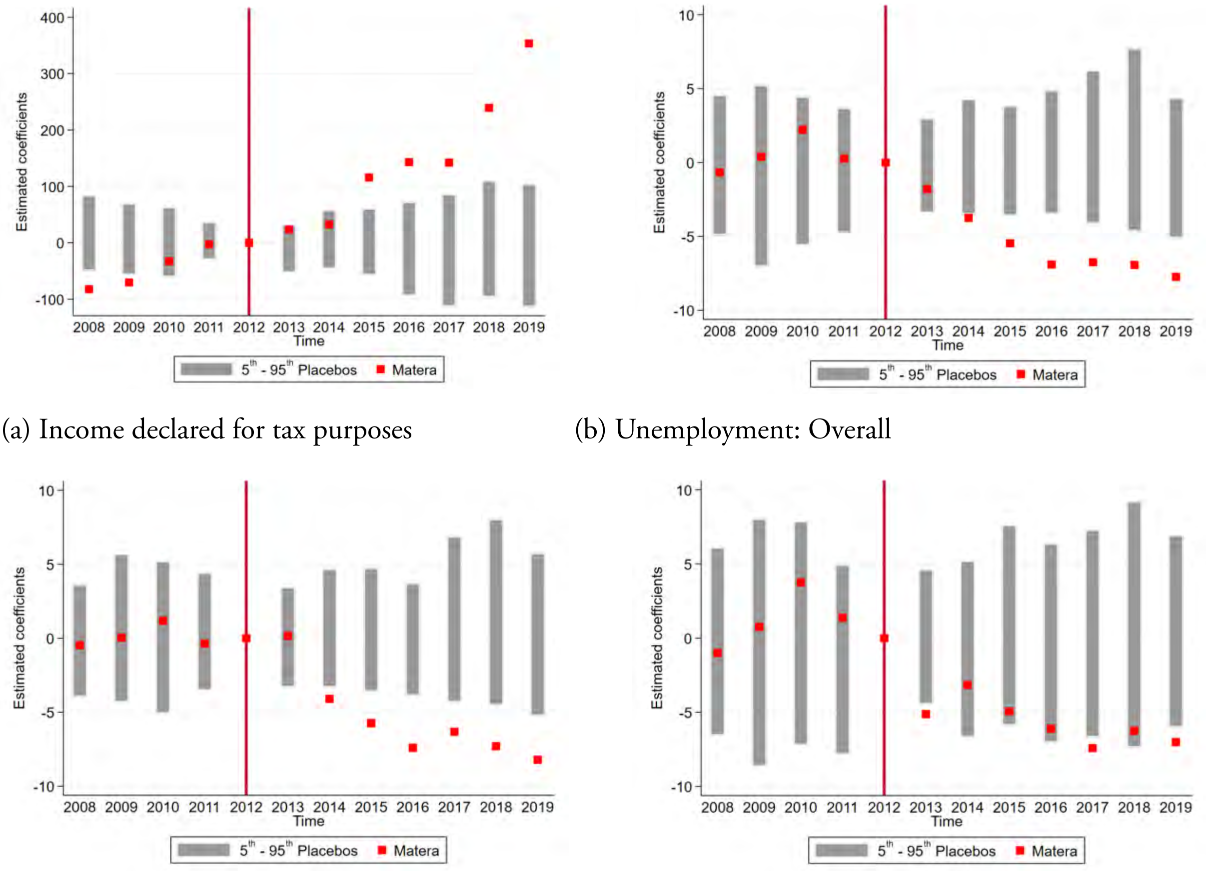
Lastly, we turn to the real estate market. We report an increase in the number of firms active in real estate trading, up to +0.08 per thousands inhabitants in 2015, or 16 additional firms (+30%). The timing of these effects matches evidence from the number of transactions in real estate, which increases around the same time, as we show in Figure 6. Similarly, an increase in sell price for the housing market is visible beginning in 2016.

More into detail, Figure 6a shows the effect of the ECoC title on the number of real estate transactions standardized to 2009 inhabitants. Consistently with our analysis by ATECO sectors, our estimates point towards an increase starting from early 2015, peaking in late 2017 to +0.74 per thousands inhabitants, or 148 additional transactions. This is equivalent to a 172% increase in 2017 once compared to the pre-treatment value of 86.1 transactions in the third quarter of 2013.

The rise in the number of transactions translates into an increase in average sell prices (euro per square meters). Figure 6b shows a generalized, i.e. across all areas and building categories in

Matera, increase in prices following the ECoC shortlisting and nomination, building up and becoming statistically significant as we approach the event year. According to our estimates, the average increase amounts at +155 €/m^2 from a pre-treatment level of 1,183 €/m^2, or +13%. As detailed in Section 3, the housing market data allows for an in-depth analysis within a city's real estate markets, namely areas, i.e. collections of neighbourhoods grouped according to the distance to the city centre, and building category, such as residential buildings, retail or office space. Moreover, given the availability of biannual data, our analysis can also dig deeper in the timing of the effects. As Matera was shortlisted in November 2013, we consider the second semester of 2013 as the first period to be treated when analyzing the real estate market. Panel A of Figure 6 investigates the previous result in more detail, by looking at average sell prices in the city centre and in areas immediately close to the city centre (right figure). Our estimates show an increase slightly under 344 €/m^2 for properties in the city centre and of 147 €/m^2 for buildings located immediately close to the city centre, up from a pre-treatment level of 1,444 and 1,151 €/m^2 respectively, in the first semester of 2013. Panel B and C break these results further by investigating prices for different types of buildings in the- and close to- the city centre. Our estimates show how the effects for the city centre can be traced back to a boom in prices for residential units and, to a somewhat lesser extent, low cost residential units (+356 €/m^2, or +25%), retail space (+856 €/m^2, or +30%) and office space (+408 €/m^2, or +38%). Indeed, residential units in Matera's city centre appreciate by 733 €/m^2, which amounts to +43% from 1,712.5 €/m^2 in the first semester of 2013. When looking at the real estate market close to, but not in, the city centre, instead, we find an increase in prices only for housing units, both normal and low cost, and no evidence of an effect for office and retail space. The increase in average sell price is nonetheless substantial for low cost residential units, reaching +457 €/m^2, up from a 1,225 €/m^2 pre-treatment level. Overall, our results are consistent with a tourism-driven increase in transactions and prices. Indeed, Picascia, Romano and Teobaldi (2017) estimate that a staggering 25% of the entire housing stock in the historical centre of Matera was listed on Airbnb as "entire place" in 2016. As the number of residential units in both the historical centre and the traditional area of Sassi is fixed, the pressure of visitors inflows is likely to have played a role in the dynamics of the housing market. Moreover, we find no evidence of an effect as we move further away from the historical city centre or as we analyze building categories unrelated to tourism, such as industrial buildings and warehouses. Said building categories and areas do not experience an appreciation, and are thus the reason for the average city-wise increase in sell prices lying lower than the increase we found for the city centre or for specific building categories.

FIGURE 4 • TAXABLE INCOME AND UNEMPLOYMENT



(a) Income declared for tax purposes

(b) Unemployment: Overall

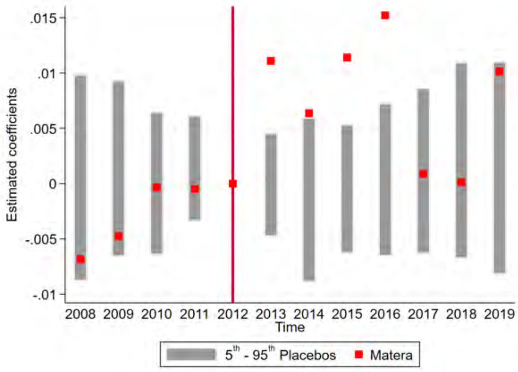
(c) Unemployment: Male

(d) Unemployment: Female

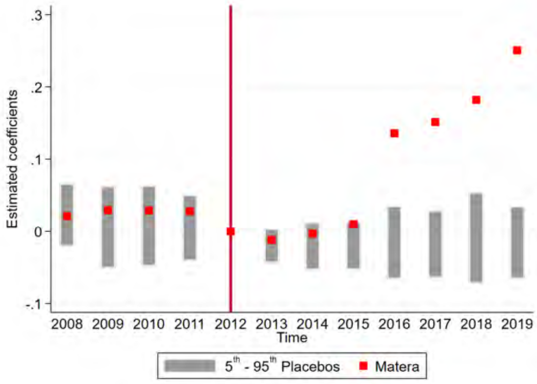
Notes: The figure shows estimated coefficients for Matera, in red, and results from permutations, in grey. The grey bar for each coefficient reports the range of estimates between the 5th and the 95th percentiles of the placebo distribution. This allows claiming statistical significance, at 10%, whenever the coefficient for Matera lies outside the grey area. We signal with a magenta vertical line pre-treatment year 2012, i.e. the year immediately before Matera's shortlisting in 2013.

FIGURE 5 • NUMBER OF FIRMS (LEFT) AND WORKERS (RIGHT) BY ATECO SECTOR

Panel A: Libraries, archives, museums and other cultural activities

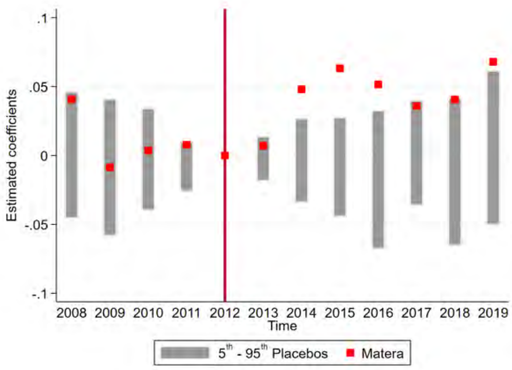


(a) Firms

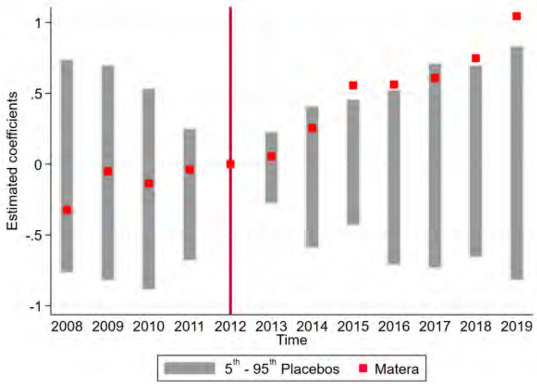


(b) Workers

Panel B: Hotels and similar accommodation

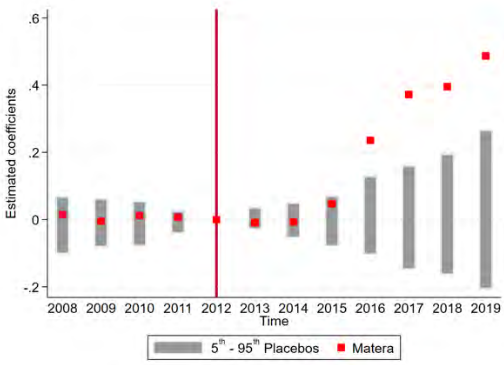


(c) Firms

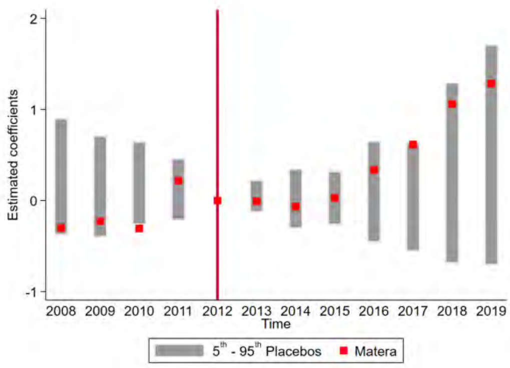


(d) Workers

Panel C: Holiday and other short-stay accommodation

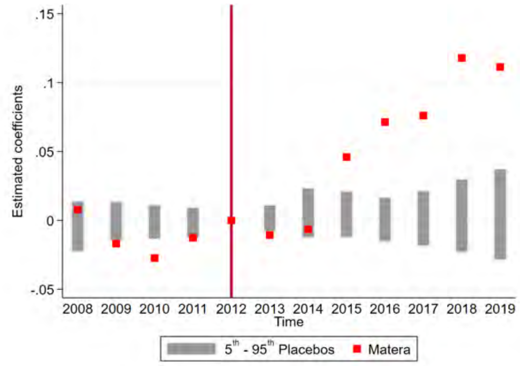


(e) Firms

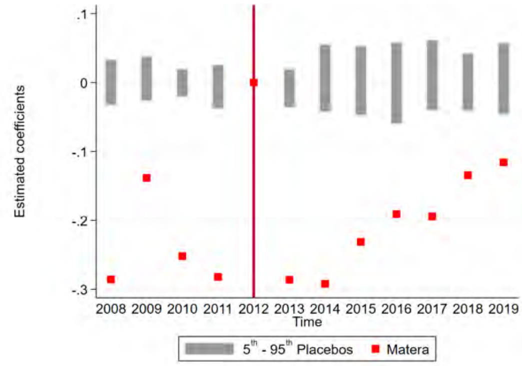


(f) Workers

Panel D: Other reservation service and related activities

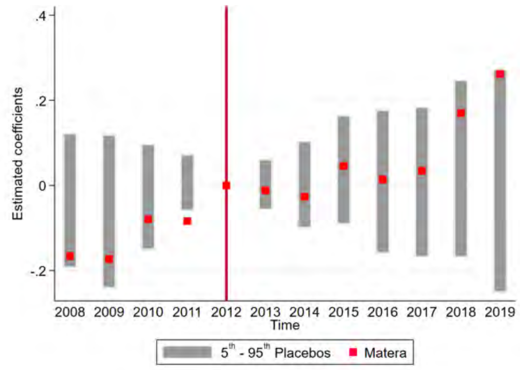


(g) Firms

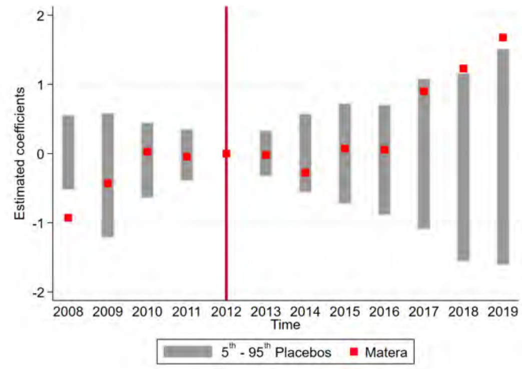


(h) Workers

Panel E: Restaurants and mobile food service activities

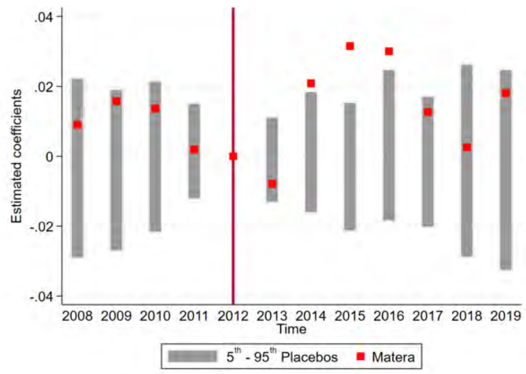


(i) Firms

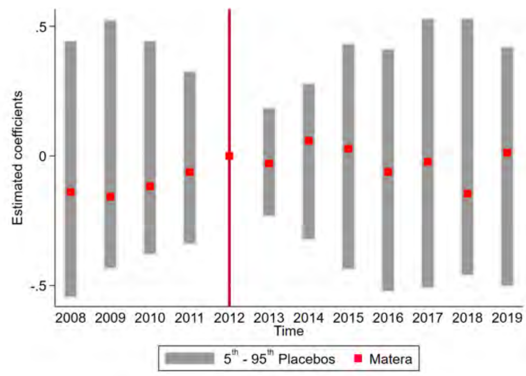


(j) Workers

Panel F: Event catering and other food service

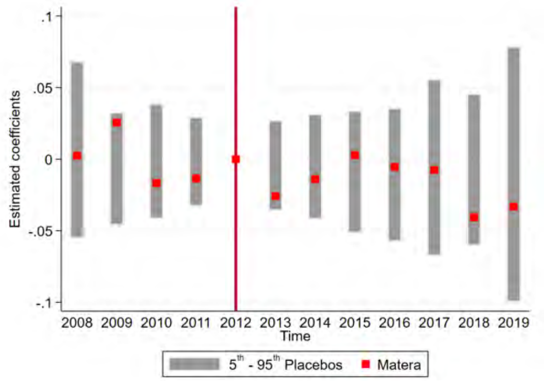


(k) Firms

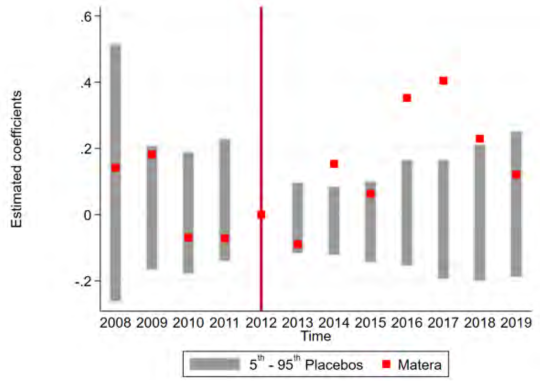


(l) Workers

Panel G: Demolition and site preparation

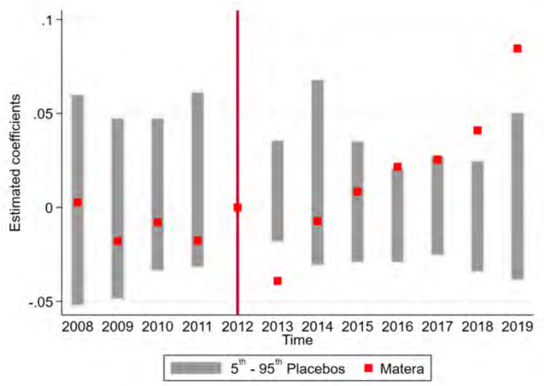


(m) Firms

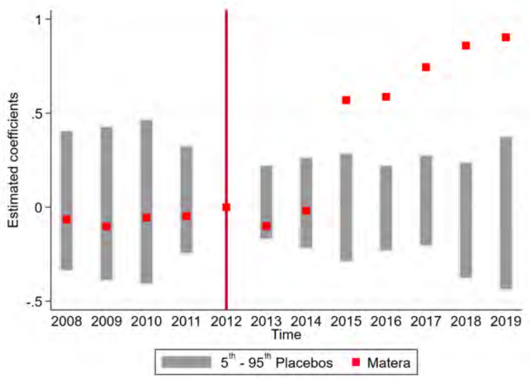


(n) Workers

Panel H: Other specialised construction activities

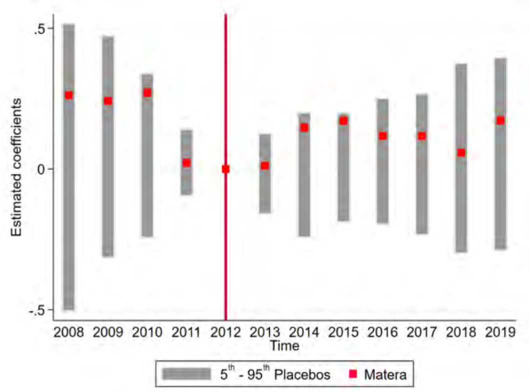


(o) Firms

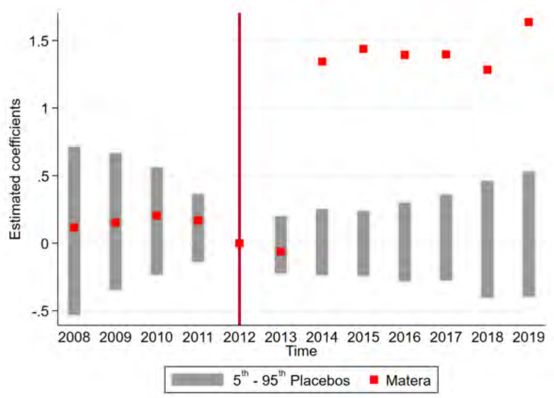


(p) Workers

Panel I: Architectural and engineering activities and related technical consultancy

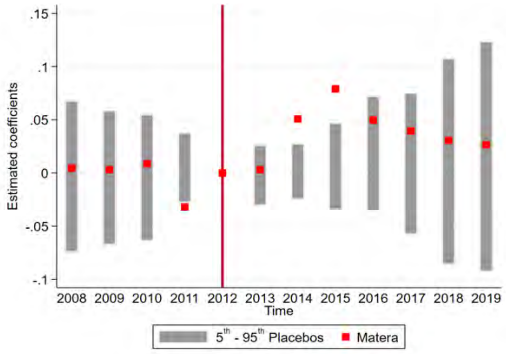


(q) Firms

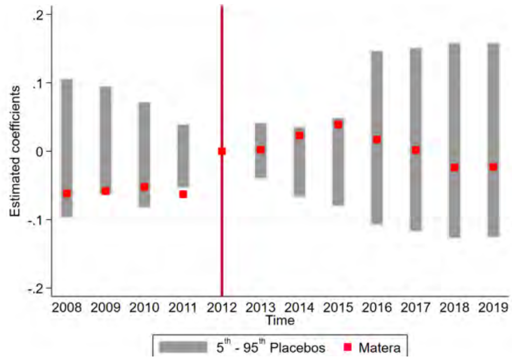


(r) Workers

Panel J: Real estate activities on a fee or contract basis



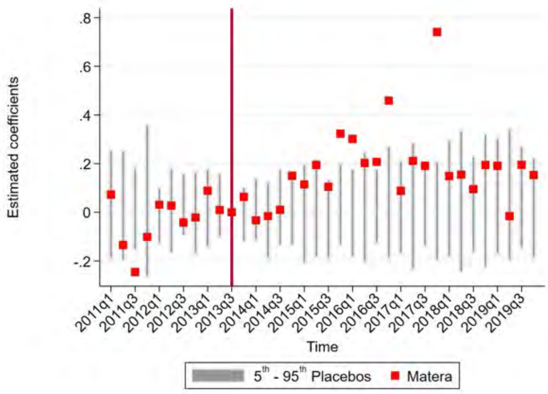
(s) Firms



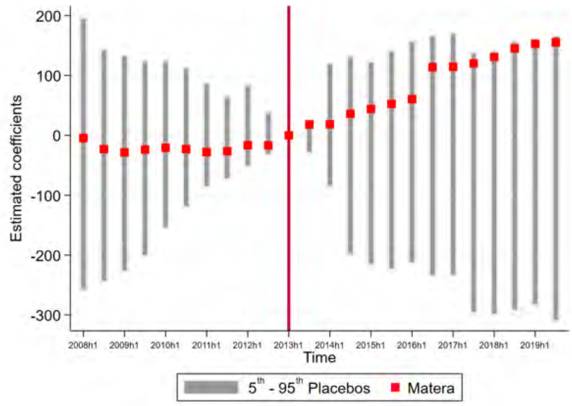
(t) Workers

Notes: The figure shows estimated coefficients for Matera, in red, and results from permutations, in grey. The grey bar for each coefficient reports the range of estimates between the 5th and the 95th percentiles of the placebo distribution. This allows claiming statistical significance, at 10%, whenever the coefficient for Matera lies outside the grey area. We signal with a magenta vertical line pre-treatment year 2012, i.e. the year immediately before Matera's shortlisting in 2013. Outcome variables are standardized per thousand inhabitants.

FIGURE 6 • HOUSING MARKET

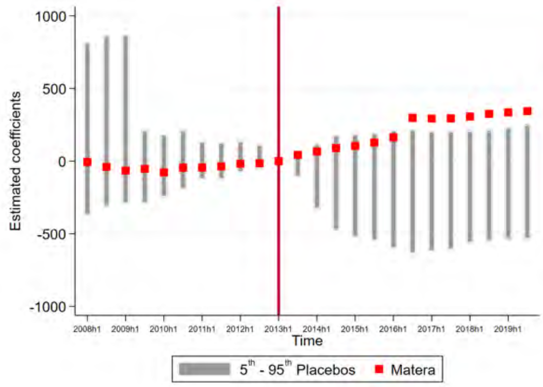


(a) Overall transactions

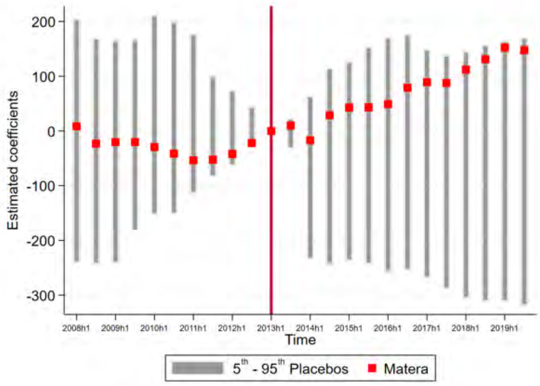


(b) Sell price: Overall

Panel A: Sell price, by areas

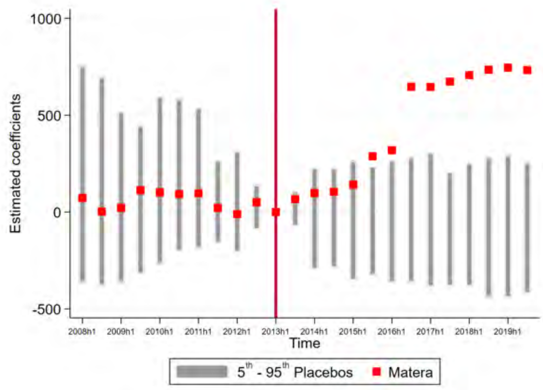


(c) City centre area

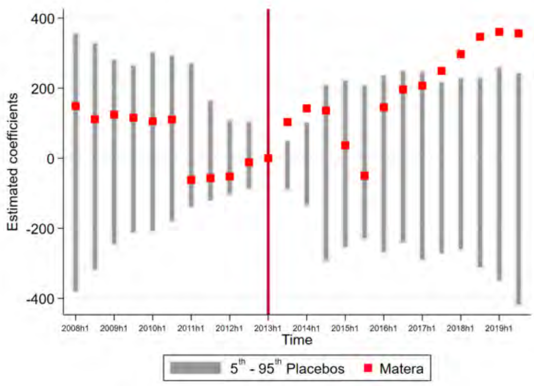


(d) Close to the city centre area

Panel B: City centre, sell price by building category

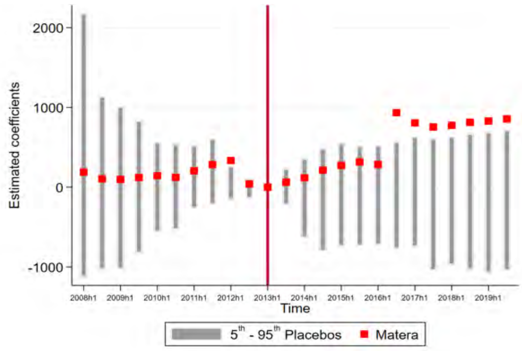


(e) Residential units

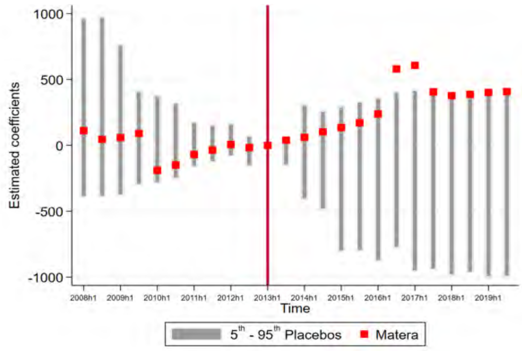


(f) Low cost residential units

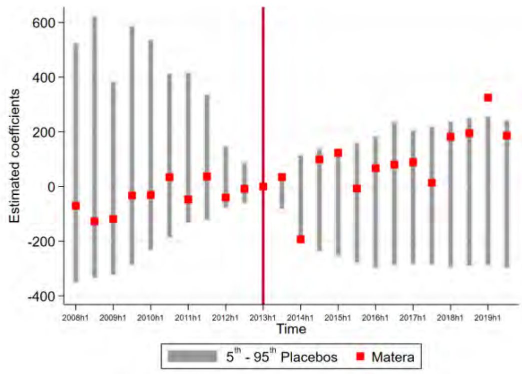
Panel C: Close to the city centre, sell price by building category



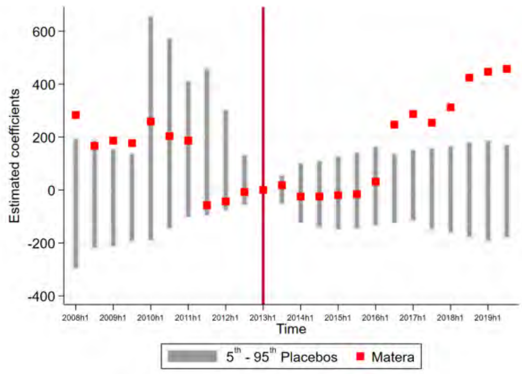
(g) Retail space



(h) Office space



(i) Residential units



(j) Low cost residential units

Notes: The figure shows estimated coefficients for Matera, in red, and results from permutations, in grey. The grey bar for each coefficient reports the range of estimates between the 5th and the 95th percentiles of the placebo distribution. This allows claiming statistical significance, at 10%, whenever the coefficient for Matera lies outside the grey area. We signal with a magenta vertical line pre-treatment year 2012, i.e. the year immediately before Matera's shortlisting in 2013. Outcome variables are standardized per thousands inhabitants.

6. Robustness checks

Table A.5 and Table A.6 in the online Appendix report a set of robustness checks. As discussed above in Section 4, the main identification assumption behind our event study specifications requires parallel trends in the potential outcomes of the dependent variable. While the assumption cannot be tested, we report coefficients associated with lead effects in the results for our main specification above. For most outcomes these coefficients are small and not statistically significant, suggesting that the parallel trend assumption is likely to hold. For other outcomes, instead, they seem to point to a violation of the assumption. This appears to be particularly relevant for hotel clients (Figure 3a), taxable income (Figure 4a), ATECO sectors such as reservation services and restaurants (Figures 5g and 5i), low cost residential units close to the city centre (Figure 6j) and, to a minor extent, also for unemployment as in Figure 4b. To tackle these concerns we re-run our main specification adding province-specific linear time trends. Quadratic province-specific time trends are added when the estimation results from the main specification hints to the presence of a quadratic pre-trend, i.e. unemployment indicators and firms in reservation services sector. Table A.5 for our economic outcomes and Table A.6 for the housing market show results for the main specification and once we add time trends. We show one sided exact p-values from permutation tests to gauge statis tical significance. Overall, our results appear robust to these corrections, as estimated coefficients appear fundamentally stable.

In an additional robustness check we also show that our results are qualitatively similar when we modify the control group as shown in Figure A.1. First, we exclude provinces bordering Matera from the control group used in the main analysis, as spillover effects could be in place. Secondly, we include in the control group all provinces in the country, thus moving away from a Southern perspective. Finally, we construct a control group composed of provinces which were shortlisted as finalists for the 2019 European Capital of Culture title alongside Matera. Results stemming from considering finalist provinces as control group should however be taken with caution for two reasons. First, finalist cities already were, unlike Matera, renown attractions and not new to media attention as we show in Figure 2b. This observation, together with the very limited sample size of a control group built on four provinces, make our assumption of parallel trends unlikely to hold in this specific instance. Secondly, all non-winning finalist cities were awarded Italian Capital of Culture (ICC) title in 2015. The ICC title, newly-created and closely related to the European Capital of Culture initiative, can be thought of as a smaller version of the European counterpart in both means and effects. All in all, Figures A.2 through A.5b contrast our original estimates with those obtained by changing the control group and show how results remain again stable across all outcomes. The only exception often being the finalist control group, for reasons outlined above.

Lastly, we provide evidence in favour of our assumption of treatment starting with the 2013 ECoC shortlisting of Matera. Indeed, one could argue that the preliminary work put in place to ensure the city was ready to submit a bid for the title might distort our results. While the coefficients on the lead effects throughout our event study specifications do not suggest strong evidence of this, in a final robustness check we force the treatment date to 2011, when the first committee supporting Matera's interest in the 2019 ECoC title was set up (Matera Basilicata 2019 Foundation, 2021). Figure A.6 through A.9b in the online Appendix show that our overall conclusions remain qualitatively similar.

7. Conclusions

We investigate the causal link between hosting a mega cultural event, tourism and economic development. In particular, we estimate the impact of being shortlisted for, and subsequently winning, the European Capital of Culture title for Matera, a previously not-so-touristic city. We find a boost in touristic presence, with check-ins and number of nights spent by tourists increasing by 115% and 52%, respectively. The local economy benefits from this growth in tourism, with a 7.74 percentage points decrease in the unemployment rate and a 9.7% increase in taxable income. Furthermore, we find evidence of an increase in economic activity in tourism-related industries and in value and transactions in the housing market.

We document heterogeneous effects in time, with the estimated positive effects for the local economy slowly yet steadily increasing and building up from shortlisting to the event year. Such a pattern is compatible with a spotlight effect: Matera's showcase as a finalist led to tourists rediscovering its cultural endowment even before hosting the event or winning the title. We present inference drawn from permutation tests. After estimating treatment effect for Matera, we reassign treatment to each unit in the control group. Exact p-values are computed augmenting the distribution of placebo treatment effects with effects found for Matera. This provides for inference which does not suffer from a downward bias in clustered standard errors due to there only being one treated cluster. Finally, focusing on one specific event allows us to have a clear measure of treatment through sound methodology and numerous potential outcomes, with little risk of other events concurring in treatment. Matera allows us to circumvent the general difficulty in combining credible identification strategy and a large, general setting which is often found in similar scenarios.

Adding to the tourism-led growth hypothesis literature, we provide new evidence on the positive causal link between the European Capital of Culture title and the local labour market. Our results also show how said positive effects are not limited to the tourism industry, but spill over to the culture and construction sectors. Similarly, our estimates speak to the stream of literature studying the relationship between tourism and the housing market. We show how a mega event is successful in increasing the number of transactions, the number of companies working in real estate and the average sell price for properties in or close to the historical city centre.

All in all, we find that the European Capital of Culture event was successful in spurring cultural regeneration and economic development for Matera, true to the goals set by the European Commission. Our findings suggest that the European Capital of Culture event could be a viable way for culturally endowed yet underrated destinations to showcase their attractions. An increase in tourism and overall economic development could then follow, even before the onset of the event, through what we call the spotlight effect. The same rationale could be applied to similar cultural events showcasing an area's beauties, such as recent national Capital of Culture initiatives. Generalizability of our results is however limited, as the spotlight effect is unlikely to apply to already well-known localities, however culturally rich.

8. References

2019 European Capital of Culture Selection Panel (2014), *Selection of the European Capital of Culture in 2019 in Italy*

Abadie A. (2019), *Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects*, «Journal of Economic Literature»

Abadie A., Athey S., Imbens G.W. and Wooldridge J.M. (2020), *Sampling-based versus design-based uncertainty in regression analysis*, «Econometrica», 88, 1, pp. 265-296

Abadie A., Diamond A. and Hainmueller J. (2010), *Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program*, «Journal of the American statistical Association», 105, 490, pp. 493-505

Abadie A. and Gardeazabal J. (2003), *The Economic Costs of Conflict: A Case Study of the Basque Country*, «American economic review», 93, 1, pp. 113-132

Angrist J.D. and Pischke J.-S. (2008), *Mostly Harmless Econometrics: An Empiricist's Companion*, Princeton, Princeton University Press

APT Basilicata (2019), *Matera Tourist Map and Guide*

Athey S. and Imbens G.W. (2017), *The State of Applied Econometrics: Causality and Policy Evaluation*, «Journal of Economic Perspectives», 31, 2, pp. 3-32

Baade R.A. and Matheson V.A. (2016), *Going for the Gold: The Economics of the Olympics*, «Journal of Economic Perspectives», 30, 2, pp. 201-218

Balaguer J. and Cantavella-Jorda M. (2002), *Tourism as a Long-run Economic Growth Factor: The Spanish Case*, «Applied economics», 34, 7, pp. 877-884

Bertrand M., Duflo E. and Mullainathan S. (2004), *How Much Should We Trust Differences-in-differences Estimates?*, «The Quarterly journal of economics», 119, 1, pp. 249-275

Billings S.B. and Holladay J.S. (2012), *Should Cities Go for the Gold? The Long-term Impacts of Hosting the Olympics*, «Economic Inquiry», 50, 3, pp. 754-772

Buchmueller T.C., DiNardo J. and Valletta R.G. (2011), *The Effect of an Employer Health Insurance Mandate on Health Insurance Coverage and the Demand for Labor: Evidence from Hawaii*, «American Economic Journal: Economic Policy», 3, 4, pp. 25-51

Catullo G. (2020), *L'«avventura» di Matera Capitale Europea della Cultura*, «Rivista economica del Mezzogiorno, Trimestrale della Svimez», 1-2, 2020, pp. 279-300

Cócola-Gant A. (2015), *Tourism and Commercial Gentrification*, in Proceedings of the RC21 International Conference on *The Ideal City: Between Myth and Reality, Representations. Policies, Contradictions and Challenges for Tomorrow's Urban Life*, pp. 27-29

– (2016), *Holiday Rentals: The New Gentrification Battlefront*, «Sociological Research Online», 21, 3

Cunningham S. (2021), *Causal Inference*, London, Yale University Press

Department for culture, media and sport, UK government (2011), *Government Tourism Policy*

Dritsakis N. (2004), *Tourism as a Long-run Economic Growth Factor: An Empirical Investigation for Greece Using Causality Analysis*, «Tourism economics», 10, 3, pp. 305-316

European Commission (2010), *Communication from the Commission to the European Parliament, the Council, the European, the European Economic and Social Committee and the Committee of the Regions*

– (2018), *Progress Report. Matera European Capital of Culture 2019*

– (2020a), *Creative Europe*

– (2020b), *European Capitals of Culture*

– (2020c), *Ex-post Evaluation of the 2019 European Capitals of Culture - Executive Summary*

European Commission, Directorate-General for Education, Youth, Sport and Culture (2020), *Ex-post Evaluation of the 2019 European Capitals of Culture: Final Report*, Publications Office

European Parliament and European Council (1999), *Decision no 1419/1999/EC of the European Parliament and of the Council*

– (2005), *Decision no 649/2005/EC of the European Parliament and of the Council*

– (2006), *Decision no 1622/2006/EC of the European Parliament and of the Council*

– (2014), *Decision no 445/2014/EU of the European Parliament and of the Council*

Faber B. and Gaubert C. (2019), *Tourism and Economic Development: Evidence from Mexico's Coastline*, «American Economic Review», 109, 6, pp. 2245-2293

Falk M. and Hagsten E. (2017), *Measuring the Impact of the European Capital of Culture Programme on Overnight Stays: Evidence for the Last Two Decades*, «European Planning Studies», 25, 12, pp. 2175-2191

Firgo M. (2021), *The Causal Economic Effects of Olympic Games on Host Regions*, «Regional Science and Urban Economics», 88, 103673.

Garcia-López M.-À., Jofre-Monseny J., Martínez-Mazza R. and Segú M. (2020), *Do Short-term Rental Platforms Affect Housing Markets? Evidence from Airbnb in Barcelona*, «Journal of Urban Economics», 119, 103278

Gomes P. and Librero-Cano A. (2018), *Evaluating Three Decades of the European Capital of Culture Programme: A Difference-in-Differences Approach*, «Journal of Cultural Economics», 42, 1, pp. 57-73.

Gunduz L. and Hatemi-J A. (2005), *Is the Tourism-led Growth Hypothesis Valid for Turkey?*, «Applied Eco nomics Letters», 12, 8, pp. 499-504

Heß S. (2017), *Randomization Inference with Stata: A Guide and Software*, «The Stata Journal», 17, 3, pp. 630-651

Horn K. and Merante M. (2017), Is Home Sharing Driving up Rents? Evidence from Airbnb in Boston, «Journal of Housing Economics», 38, pp. 14-24

Koster H.R., van Ommeren J. and Volkhausen N. (2021), *Short-term Rentals and the Housing Market: Quasi-experimental Evidence from Airbnb in Los Angeles*, «Journal of Urban Economics», 103356

MacKinnon J.G. and Webb M.D. (2017), *Wild Bootstrap Inference for Wildly Different Cluster Sizes*, «Journal of Applied Econometrics», 32, 2, pp. 233-254.

Maennig W. and Richter F. (2012), *Exports and Olympic Games: Is There a Signal Effect?*, «Journal of Sports Economics», 13, 6, pp. 635-641

Matera 2019 Committee (2021), *Matera Candidate City European Capital of Culture 2019*

Matera Basilicata 2019 Foundation (2021), *Matera is a Producer of Culture. Matera European Capital of Culture 2019 Monitoring Report*, «New York Times», in *52 Places to Go in 2018* (2018)

Nocito S., Sartarelli M. and Sobbrio F. (2021), *A Beam of Light: Media, Tourism and Economic Development*, «Tourism & Economic Development»

Novy, J. and Colomb, C. (2016), *Protest and Resistance in the Tourist City*, «New York Times», in *52 Places to Go in 2018* (2018)

OpenData Matera (2019), *Residenti nei rioni Sassi dal 1988 ad oggi*

Peralta S., dos Santos J.P., Gonçalves D. *et al.* (2020), *Do Short-term Rentals Increase Housing Prices? Quasi-experimental Evidence from Lisbon*, Technical report, Gabinete de Estratégia e Estudos, Ministério da Economia

Picascia S., Romano A. and Teobaldi M. (2017), *The Airification of Cities. Making Sense of the Impact of Peer to Peer Short Term Letting on Urban Functions and Economy*

Pinotti P. (2015), *The Economic Costs of Organised Crime: Evidence from Southern Italy*, «The Economic Journal», 125, 586, F203-F232

Regulation (EC) No 1059/2003 of the European Parliament and of the Council (2003)

Rognlie M. (2016), Deciphering the Fall and Rise in the Net Capital Share: Accumulation or Scarcity?', «Brookings papers on economic activity», 2015, 1, pp. 1-69

Rose A.K. and Spiegel M.M. (2011), The Olympic Effect', «The Economic Journal», 121, 553, pp. 652-677

Srakar A. and Vecco M. (2017), *Ex-ante Versus Ex-post: Comparison of the Effects of the European Capital of Culture Maribor 2012 on Tourism and Employment*, «Journal of Cultural Economics», 41, 2, pp. 197-214

Steiner L., Frey B. and Hotz S. (2015), *European Capitals of Culture and Life Satisfaction*, «Urban Studies», 52, 2, pp. 374-394

Wolfers J. (2006), Did Unilateral Divorce Laws Raise Divorce Rates? A Reconciliation and New Results', «American Economic Review», 96, 5, pp. 1802-1820

World Tourism Organization, *International Tourism Highlights, 2019 Edition* (2019), Madrid, Spain

Zimbalist A. (2020), *Circus Maximus: The Economic Gamble Behind Hosting the Olympics and the World Cup*, Washington, Brookings Institution Press

Giacomo Rosso

Local Economy, Housing Prices and Neighborhood Change

Abstract. This paper investigates the impact of real estate prices on local economic activities within cities. It combines a novel geo-located dataset of retailers and services with information on the sale and rental prices and develops an empirical strategy based on IV panel techniques to address endogeneity con- cerns. The instrument adopted is novel and unique, i.e the city heating district system. The results reveal that housing prices affect positively the variety of products and services offered in an area, and negatively the tradable and non-tradable sectors. Nonetheless, price demand-induced changes lead to a massive positive effect on all activities and the variety supplied, with varying intensities in gentrified and non-gentrified areas of the city. Moreover, the paper identifies changes in population density and composition as the main channels through which the demand side affects housing price shifts. The findings highlight the role of neighborhood change and gentrification patterns in reshaping cities.

Keywords. Housing Price, Gentrification, Local Economy

1. Introduction

How does the city structure respond to shifts in real estate prices? Cities are not homogeneous. Changes in neighborhood and local consumer demand may influence housing prices. Thus, differences in housing prices across areas can shape the availability and variety of goods and services. This can happen through two primary channels. Firstly, changes in prices may directly hit endogenous activities. Secondly, demographic and gentrification patterns within the city may lead to shifts in real estate prices and sub- sequently to local activities. The way in which city activities respond to shifts in sales and rent prices ultimately determines the significance of these channels.

In this paper, I investigate the impact of variation in real estate prices on local economic activities within urban areas and determine whether such changes have an effect on the diversity of products and services offered, as well as the balance between tradable and non-tradable sectors. Furthermore, the paper aims to distinguish between the direct effect of housing price changes and the demand-induced shifts in housing prices resulting from demographic and gentrification trends across city zones.

The research focuses on the city of Turin and covers the period from 2012 to 2019. For the analysis, I obtained a collection of unique and highly specific datasets, including semestral sale and rent asking prices at the census tract level from Idealista, as well as a list of active licenses for retailers and services in the city, which includes information on their location and category. These data are used in the empirical strategy composed of a panel fixed effects model. However, the causal effect between real estate prices and local economic activities is challenging to establish due to potential reverse causality and unobserved factors. To address this, the empirical strategy is complemented with an instrumental variable approach. The IV specification takes advantage of the unique heating district system in the city of Turin, the "Teleriscaldamento" (TLR). Given the exogenous variation in the heating unit installed across time and space, I construct an instrumental variable that counts for the power of heating units in each area. This system provides cost savings for homeowners, which is reflected both in the sale and rent prices.

The results highlight the impact of housing sales and rents on local economic activities by differentiating between the direct effect of housing price changes and the demand-induced effect. The study reveals a significant and positive effect between housing prices and the variety of local economic activities. However, when examining the impact on tradable and non-tradable sectors separately, both sectors exhibit a negative reaction to housing prices. Nonetheless, I identify a remarkable positive demand-induced effect caused by demographic and gentrification processes within the city. In areas with low to medium income levels, the impact is more significant for non-tradable activities and low-income levels for tradable activities. Likewise, in sparsely populated areas, the effect is more pronounced for tradable activities, while for non-tradable activities, the effect is more pronounced in areas with low to medium population density. Finally, the results highlight population density and in its composition as main demand side channels through which the housing price may affect local activities.

This study is situated within two distinct areas of literature: the literature on gentrification and neighborhood changes (Vigdor *et al.* 2002, Vigdor 2010, Ding and Hwang 2016, Glaeser *et al.* 2020, Brummet and Reed 2019, Stroebel and Vavra 2019, Borraz *et al*. 2021, Glaeser *et al.* 2023), and the growing body of research on urban consumption and American urban revival (Glaeser *et al.* 2001, Couture 2013, Almagro and Dominguez-Iino 2022, Davis *et al.* 2019, Baum-Snow and Hartley 2020, Couture and Handbury 2020, Behrens *et al*. 2022). Specifically, this paper is related to the work of Stroebel and Vavra (2019) and Borraz *et al.* (2021), as both investigate the relationship between the housing market and retail prices, with a focus on grocery stores. Stroebel and Vavra (2019) examines the impact of housing prices on retail prices in the USA and finds an elasticity of 15-20%. The authors assert that their estimates are not influenced by shifts in demographic or gentrification trends. Instead, they suggest that the behavior of existing homeown- ers is altered by changes in their housing wealth caused by fluctuations in house prices. This change in behavior, in turn, prompts firms to increase their markups. Meanwhile, Borraz *et al.* (2021) studies the effect of new housing stock on retail prices and product variety in Montevideo, Uruguay. According to the author's findings, local prices tend to decrease in response to an increase in demand. This can occur if there is either an increase in the number of competitors entering the market or a rise in the variety of products or services available to consumers. Unlike these previous studies, I examine the entire range of economic activities within cities.

Finally, a similar perspective is adopted by Glaeser *et al.* (2020), who examines the impact of gentrification on a variety of local economic activity sectors in five USA cities. Their measure of gentrification is based on rent growth and the poverty rate, and their results show a correlation indicating a substitution effect of tradable sectors in favour of non-tradable sectors. In a second version of the paper (Glaeser *et al.* 2023), the authors measure gentrification as the share of college students and they find that gentrifying neighborhoods experience faster growth in both the number of retail establishments and business closure rates than their non-gentrifying counterparts. I instead study the housing prices as a measure of gentrification, under specific conditions.

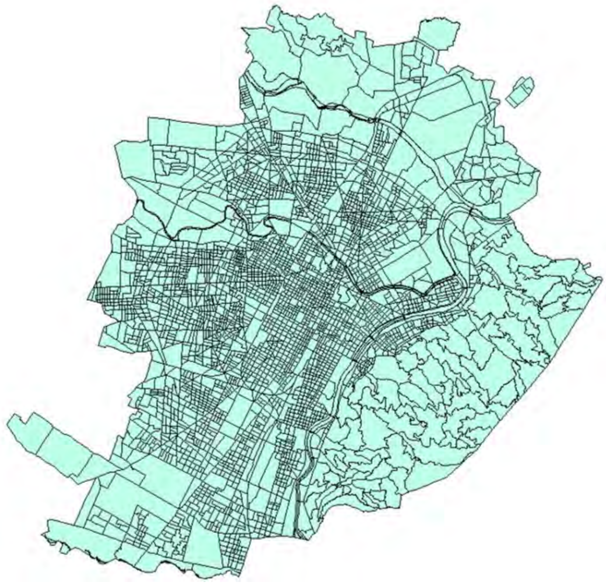
The paper contributes to the literature as follows. Firstly, it offers new insights on the relationship between real estate prices and all local economic activities, including retailers and services, by providing evidence of causal effects. Secondly, it identifies the housing price effect changes induced by demographic and gentrification patterns distinguishing different effect across city zones. Thirdly, it introduces a new and unique instrumental variable to address the endogeneity concerns, the "Teleriscaldamento". Lastly, the study shifts its attention to a European city and investigates the efficacy of several demand-induced channels in this context. This approach represents a twist from most previous literature on this topic, which has focused on examining US cities. By exploring a European city, the findings can be compared to those of previous studies, despite the notable differences between US and European urban environments.

The paper proceeds as follows. Section 2 presents the primary data sources, while Section 3 outlines the involved variables. Section 4 rationalizes the conceptual framework utilized for building the identifi- cation strategy, which is then discussed in Section 5. The results are presented and analyzed in Section 6. Finally, Section 7 provides a conclusion, including the next steps of the project.

2. Data

This paper exploits multiple and unique data sets for the empirical analysis. The primary source is the list of licenses for retailers, bars, restaurants, beauticians and hairdressers in Turin from 2012 to 2019 provided by the City Council. To open a new business or expand an existing one, the owner must request a license without any additional cost. The database includes information about the type of merchandise, location, and opening and closing dates for each license. The licenses are divided into 41 categories (see Table A.1) by the City Council. Since the request for a license is a more reliable indicator of economic activity than the opening or closing of a physical establishment, I use the opening and closing dates of the licenses to construct a variable that counts the number of active licenses per semester and category.

FIGURE 1 • TURIN DIVIDED IN CENSUS TRACKS



Notes: The plot shows the census tracks, namely the spatial unit used in the baseline specification.

FIGURE 2 • TLR NETWORK SNAPSHOT

Notes: The orange lines are the TLR pipelines and the black points are the heat- ing units.

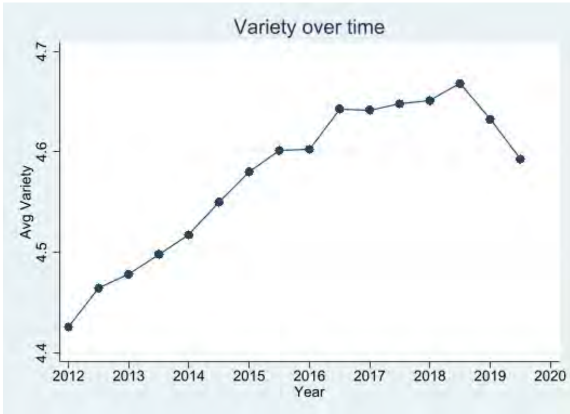
Secondly, the data for both house and rental prices come from Idealista, a popular online real estate platform in Italy. The data is semestral, covering the years 2012-2019, and reports the "median asking price" per squared meters at the census track level. This median is computed by taking the mean of prices listed on the platform once the outliers and duplicated advertisements have been removed, therefore it may not reflect the final market price for either houses or rentals. These measures have advantages and disadvantages. On one hand, it does not allow for a direct comparison of posted prices with actual prices. Despite this, Chapelle and Eyméoud (2022) have shown that posted prices can be a good indicator of actual prices. Moreover, since bargaining is a common part of the buying and renting process, the asking price could show the house owner's attempt to monetize several possible features related to the house or the neighborhood.

Thirdly, I use data on the Teleriscaldamento (TLR) district heating network, operated by Iren, a company that provides electricity, natural gas, and other products and sectors to individuals, companies, and public entities. In the 1970s, Iren sought to utilize the waste heat generated by its electricity pro- duction plants to heat water for buildings. To achieve this, the company began constructing a pipeline system to connect its plants to its customers. Firstly, Iren started connecting the closed plant area and subsequently in several parts of the city. The network currently covers about 50% of the city and includes both the pipeline infrastructure, PIs, and heating units (or boilers), HUs, installed in buildings connected to the system. One HU can serve either one or more surrounding buildings according to the agreements taken between the company and the building administrators. Each HU has a defined power, whose ca- pacity depends on the dimension of the buildings served. If a building administrator, appointed by the apartment owners, chooses to utilize the service, they must contact the company. The company will offer various options that typically do not involve any installation fees for the HU. The TRL's HU will replace the existing centralized HU and all management and maintenance costs will be covered by the company. Table A.2 reports a list of costs avoided thanks to the TLR system. However, this cost savings opportu- nity is only available if the building already has a centralized HU, as the replacement would not be feasible otherwise. For instance, TRL's HU can not be used in cases where the building has autonomous HUs, since one autonomous HU is located in each apartment. The data set, directly provided by Iren, is com- posed of the entire system, both PI and HU. Due to the sensitive nature of these data for the company, all subsequent representations of the data will be in aggregate form at the census track level. To provide an idea of the granularity and detail of the data, a small sample is shown in Figure 2. For each HU, the data set includes in- formation such as its coordinates, installation date, and power in kilowatts for residential HU only.

FIGURE 3

Notes: The graph plots the incremental variation over time of sale and rent price with respect to 2012, with the standard deviation per semester.

FIGURE 4



Notes: The graph plots the evolution of the activi- ties' variety over time. The value is the areas' aver- age.

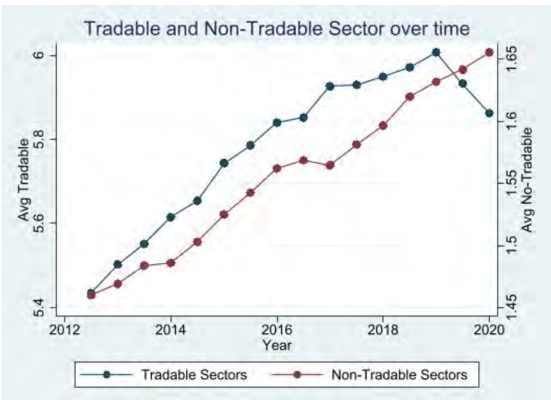


FIGURE 5

Notes: The graph plots the evolution of the activ- ities over time, divided into tradable good sellers and non-tradable services providers. The value is the areas' average.

Lastly, I supplement the primary data sets with additional information that includes time-variant socio-demographic variables from the Turin City Council's statistical department, as well as some time-invariant characteristics from the 2011 National Census.

3. Descriptive statistics

This study is conducted in Turin, Italy, and focuses on 3850 census tracks (see Figure 1) within 23 different neighborhoods. The analysis covers the period from 2012 to 2019, during which the city experienced a significant decrease in real estate prices (see Figure 3), following the average national trend. Over the period of 2012 to 2019, sale prices experienced an average decrease of nearly 25%, with a steeper de- cline observed from 2012 to 2014, followed by a more gradual decline. Similarly, rent prices also decreased, hitting a low point of approximately -15% in 2016. Although the rental prices agreed upon through such arrangements reflect market trends, they exhibit significantly less variation compared to sale prices, indicating a more uniform distribution of prices within the city.

Contrarily, the average number of local economic activities significantly increases over the same pe- riod. Figure 5 illustrates the evolution of tradable and non-tradable sectors over time, with non-tradable sectors being bars, restaurants beauticians and hairdressers, and tradable goods being everything else. The two types of sectors show a similar trend until the latter half of 2018 when tradable sectors experienced a sharp decline. The variety of different goods and services for residents also follows a similar trend, with a consistently increasing supply until a few years before the pandemic when the trend turns. Anecdotally, this decrease in establishments number follows the European trend already started before the pandemic and continued even after (see Figure A.1, A.2 and A.3).

4. Conceptual framework

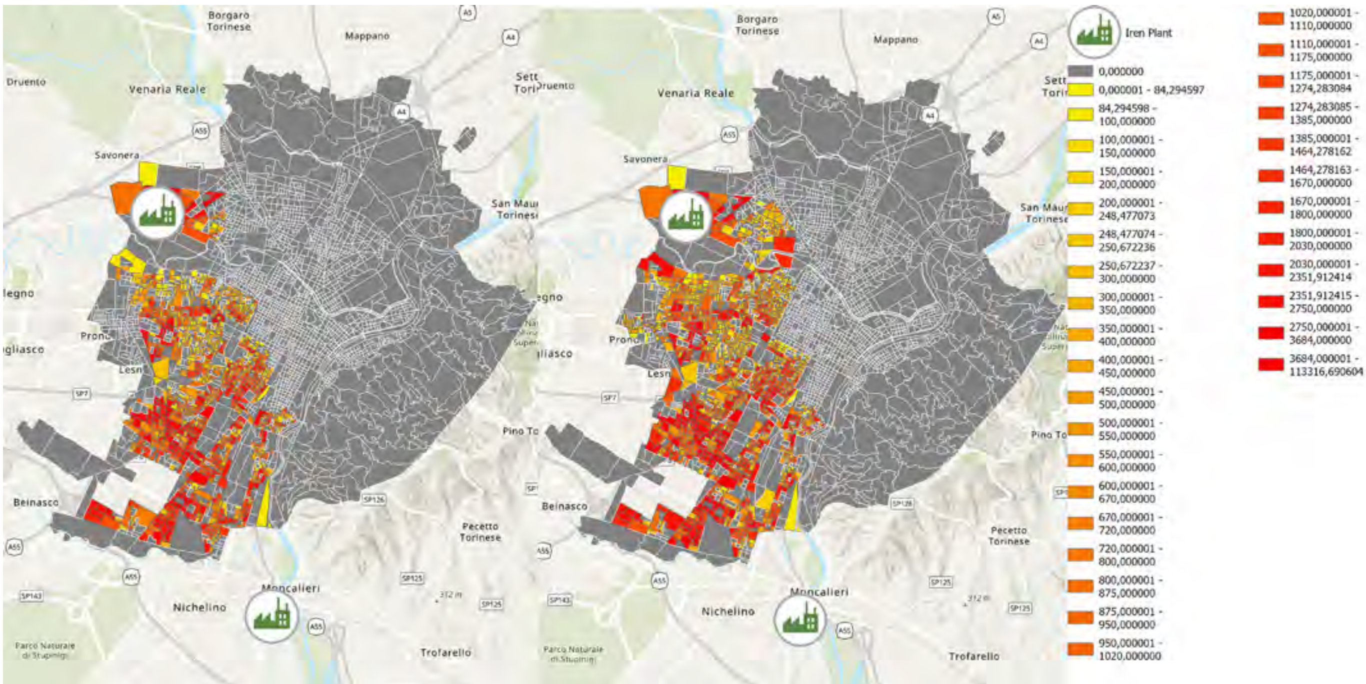
This section presents a conceptual framework to explain how housing prices may impact local economic activities. Additionally, the framework provides guidance for empirical analysis, including considerations around model specification, potential threats to identification, estimation strategies, and the interpretation of results.

I assume two plausible channels through which housing price variation may occur and consequently the effect on the local economic may differ.

Indirect Effect. The first channel is the *Indirect Effect*, which refers to changes in housing prices re- sulting from shifts in demand. Such changes may stem from gentrification processes that alter the average income in the area, such as shifts in population density, population composition, consumer behaviours, or a combination of these factors. Assuming that demand increases, this would lead to an increase in housing prices, thereby boosting the profits of local economic activities. As a result, both tradable good sellers and non-tradable service providers may see an increase in the number of activities due to positive profits. Given this increase in activities, it is plausible to assume that the variety of activities provided in the area should also increase.

Direct Effect. The second channel, the *Direct Effect*, identifies the unambiguous impact of housing prices on the endogenous consumption amenities in the city. Unlike the *Indirect Effect*, this channel is not influenced by any other confounding factors. Therefore, an increase in housing prices would lead to higher costs for activities, such as higher rental costs, which may cause marginal activities to exit the market, while incumbents may not enter the market. The effect on the variety of activities in the area is less predictable since the impact induced by demand shifts is not considered.

FIGURE 6 • A) KWATT OF TLR SUPPLIED IN 2012 (LEFT) - B) KWATT OF TLR SUPPLIED IN 2019 (RIGHT)



Notes: Distribution of TLR across the city, the colour of the census tracks is proportional to the power of TLR supplied in the area. The grey area does not have TLR.

5. Empirical strategy

The objective of this study is to determine the impact of real estate prices on urban economic activity. In Section 4, I presume two possible channels that may result in a shift in the activities distribution, the *Direct* and *Indirect Effect*. The baseline specification aims to identify *Direct Effect*, therefore I rely on the following panel fixed effect model:

$$Y_{ikjt} = \beta log(P)_{ikjt} + \gamma X_{ikjt} + \mu_k + \delta_j + \tau_t + \theta_{jt} + \epsilon_{ikjt} \quad (1)$$

The dependent variable is denoted by *log(Y)ikjt*, which is the logarithm of the outcome variable in a specific census tract *i* and neighborhood *k*, at a given semester *j* and year *t*. The independent variable of interest is denoted by *log(P)ikjt*, which is the logarithm of housing prices in the same census tract *i* and neighborhood *k*, at semester *j* and year *t*. Since the rent market price is regulated, the focus is on sale prices. The model includes semester and year fixed-effects, denoted by δ_j and τ_t, respectively. ϑ_{jt} refers to the interaction between the semester and year fixed-effects. While the observations in this study are at the census track level, the model incorporates neighborhood fixed-effects, represented by μ_k, as gentrification changes typically occur at the neighborhood level (Vigdor *et al.* 2002). However, I include a set of control variables, X_{ijt}, at the census tract level, to control as possible for differences across census tracts and to rule out as much as possible the *Indirect Effect*. The control variables account for differences such as sociodemographic time-variant characteristics, including the share of foreign residents, young residents (ages 0-30), old residents (over 66 years old), the natural logarithm of population density, and the natural logarithm of the number of families. Additionally, the model includes several time-invariant census tract features from the 2011 National Census, such as the level of education and residential building composition in the area. As a result, β represents the *Direct Effect*.

Eq. 1 has been applied to several outcome. The primary objective of the analysis is to examine the impact of housing prices on the availability of diverse products and services in an area, as it can significantly affect residents' welfare. To achieve this, a variable is constructed, defined as the share of category variety and computed as the number of categories experienced in an area divided by the total number of categories in the dataset. Secondly, the focus shifts to the composition between tradable good sellers and non-tradable service providers, examining changes in their levels due to fluctuations in housing prices.

When trying to identify the causal relationships in Eq. 2, a major concern arises due to endogeneity. Indeed, housing prices may be affected by local economic factors and the variety of products and services available to consumers. Additionally, they may be correlated with unobservable characteristics and census tract specificities, which are grouped into the error term. To address these endogeneity issues, an instrumental variable approach is implemented. This approach leverages the variation in time and space of TLR in terms of power supplied in a given area. The intuition relies on the fact that TLR represents a more cost-efficient option than centralized heating systems (see Table 2). As a result, individuals selling or renting a house may try to capitalize on these savings by raising their asking price. Furthermore, the capitalization effect is expected to be stronger when the amount of kilowatts supplied in the area is higher.

The first stage regression assumes the following structure:

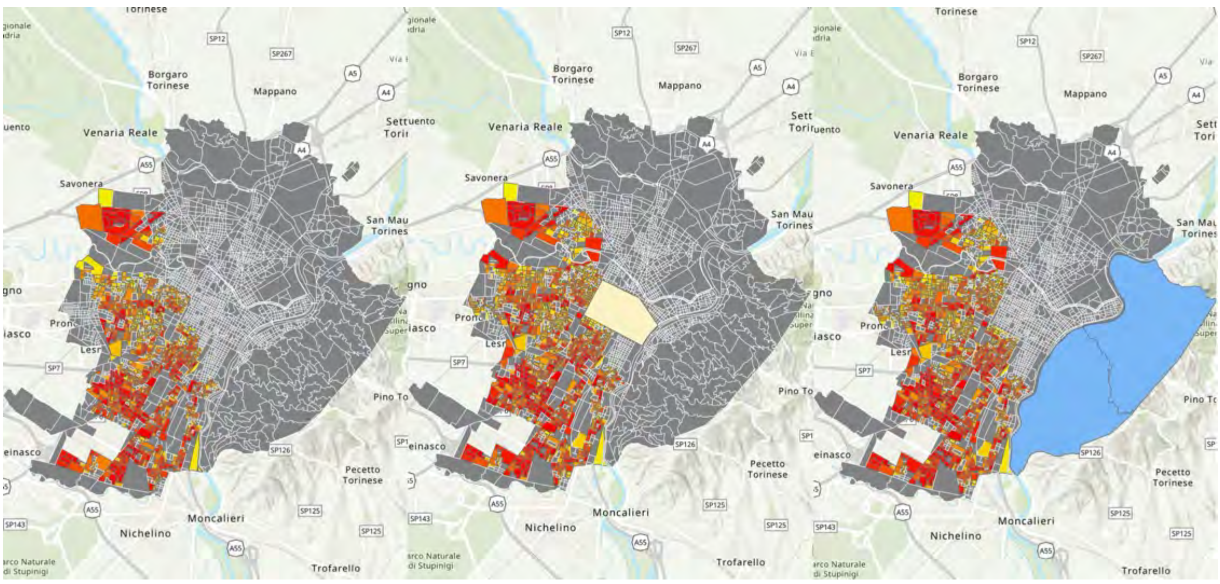
$$log(P)_{ikjt} = \omega\gamma log(TLR)_{ikjt} + X_{ikjt} + \mu_k + \delta_j + \tau_t + \theta_{jt} \tag{2}$$

where $log(TLR)_{ikjt}$, is computed as the logarithm of the whole HUs power supplied in the census tract. Following the intuition, the coefficient should display a positive effect of TLR on the sale price. Moreover, to test the relevance of the instrument, I provide the F-test of excluded instruments which is well above 10, the standard rule of thumb accepted (Angrist and Pischke 2009). Thus, by employing the instrumental variable approach, Eq. 2 reveals the Direct Effect of the compliers. Standard error are clusterized at the level of the instrument's variation (Abadie *et al.* 2023).

Figure 6 demonstrates how the instrumental variable varies over time and across space during the period analysed. Starting in the 1970s, the TLR was initially constructed to link Iren's plants, creating a network that could connect both facilities. From 2012 to 2019, the firm expanded the system to cover multiple areas in the western part of the city and extended it to the northern zone. Additionally, the intensity of power supplied varied over the years in the census tracks that were already supplied.

The exclusion restriction requires that the TLR power in area i affects the outcome variable solely through its variation in selling or renting price. However, this requirement would be violated if the TRL construction was prioritized based on areas either with higher levels of income or more/less gentrified in general. Nevertheless, this scenario seems unlikely, because the company clearly states that the construction of TLR was determined by a thorough assessment of the costs involved in laying the pipeline and a market analysis of potential customers, specifically those buildings that can convert from centralized HU. This viewpoint is further supported by graphical evidence in Figure 7. The figure shows that Iren made rational decisions to avoid certain areas of the city, such as the Centro and the hilly areas, even though they are some of the richest areas of the city, as shown in Table A.3. Specifically, TLR was not constructed in the neighborhood of Centro, the city centre (see Figure 7b), due to the numerous historical landmarks in the area, which could result in costly delays in construction due to archaeological discoveries.

Figure 7 • (a) kWatt of TLR supplied in 2019 (left) - b) plus the neighborhood Centro (in the middle) - (c) plus the hilly part of the city (right)



Notes: The three plots show the TLR distribution across the city, the colour of the census tracks is proportional to the power of TLR supplied in the area. The grey area does not have TLR. (b) The yellow area is the "Centro" neighborhood of the city. (c) The blue area is the hilly neighborhood of the city.

Similarly, Iren did not expand the TLR network in the hilly part of the city (see Figure 7c) due to the high cost associated with the area's morphological structure.

Another issue arises from Figure 7a, since the instrument may not be randomly assigned among census tracts within the same neighborhood. This is because several census tracts in neighborhoods served by TLR may not be connected to TLR due to either lack of demand in the area (i.e., a census tract with only a public park and no residential buildings) or specific consumer choices or characteristics. To ensure the random assignment of the instrument, Eq 2 includes several control variables, X_{ikjt} that account for the differences across census tracts.

6. Main results

The organization of this section is as follows. First, I present the initial findings from the first stage analysis, examining both sale and rent prices. Second, I present the baseline results for the considered outcome variables. Third, I investigate how the effects vary for all outcome variables by subsampling the dataset in response to differences across the city. Finally, I conduct an empirical analysis to assess the plausibility of potential mechanisms that could drive changes in demand and results in in housing prices.

TABLE 1 • FIRST STAGE OF IV ESTIMATES - TLR VERSUS SALE AND RENT PRICES

	(1) First Stage - Sale	(2) First Stage - Rent
log(TLR)	0.0045***	-0.0005***
	(0.0002)	(0.0002)
Sociodem. Control	Yes	Yes
Census 2011 Control	Yes	Yes
Buildings Control	Yes	Yes
Semester FE	Yes	Yes
Year FE	Yes	Yes
Semester*Year FE	Yes	Yes
Neighborhood FE	Yes	Yes
Number of Obs.	61568	61568
KP F-statistic	580.593	10.169

TABLE 2 • OLS AND IV ESTIMATES - SHARE OF VARIETY VERSUS SALE PRICE CHANGES

	(1) OLS	(2) IV	(3) IV
log(Sale Price)	0.0178***	2.4113***	0.1357***
	(0.0030)	(0.1292)	(0.0340)
Sociodem. Control	Yes	No	Yes
Census 2011 Control	Yes	No	Yes
Buildings Control	Yes	No	Yes
Semester FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Semester*Year FE	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes
Number of Obs.	61568	61568	61568
Mean in 2019	0.1120	0.1120	0.1120
1% Increase wrt Mean	0.15%	21.5%	1.2%

Notes: The Table reports the OLS and IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. Controls are grouped in i) Sociodem. Control includes the share of foreign residents, the share of young residents (0y-30y), the share of old residents (more than 66y), the log of population density, the log number of families; ii) Cesus 2011 Contr includes the share of illiterates people in 2011, the share of people with a primary school licence in 2011, the share of people with secondary school license in

2011, the share of undergraduate people in 2011, the share of graduate people in 2011, and log of families in rent apartment in 2011; iii) Building Control includes the log number of residential buildings in 2011, log number of residential building construction in the 80s, log number of residential building construction in the 90s, log number of residential building construction in the 00s.

6.1 First stage results

Before proceeding to the regression results, Table 1 displays the first stage results, Eq. 2, both for sale and rent prices, in their most demanding specification, including semester, year, semester-year, and neighborhhod fixed effect, beyond sociodemographic, 2011 National Census and Buildings controls. The results for sale prices are as expected, indicating that an increase in the instrumental variable leads to an average rise in sale prices. This finding supports the intuition that housing owners attempt to capitalize on their cost savings through the TLR. Additionally, the instrument appears to be strong, with an F-statistic considerably greater than 10. In contrast, column (2) reports a less consistent outcome. Changes in TLR power in the area seem to imply an average negative effect on rent prices, and the instrument loses power compared to the previous case. Nevertheless, this result is also expected since the rental price market is regulated, and the instrument's loss of power is predictable.

6.2 Baseline results

The expected results, as rationalized in Section 4, are presented in the following findings. Table 2 displays the outcomes of a panel fixed effect model (Eq. 1), which examines the impact of sale price on the share of product/service varieties within cities. The dependent variable is defined as the ratio of the number of single categories provided in the area to the categories exhibited in the dataset. The OLS coefficient, Column (1), is positive and significant, but suffers from reverse causality and omitted variable bias. Therefore, Columns (2) and (3) integrate the instrumental variable approach to solve these issues and report the IV results, which capture the effect on the compliers. Column (3) presents the *Direct Effect* of the sale price on variety, accounting for demand differences across areas through the control variables. The findings indicate that a 1% increase in sale price leads to a significant 0.0013 units increase in share variety, representing a 1.2% variation in the variety share mean. In contrast, Column (2) combines the *Direct* and *Indirect Effect* of the sale price on the compliers, with no control variables. The baseline specification in the instrumental variable extension, Eq. 2, uses control variables to tackle demand-induced effects on the housing price shift and control for heterogeneous characteristics across census tracks. As a result, the coefficient is biased and serves as an upper bound. The outcome is still positive and significant, but the effect is more than 20 times greater than that of Column (3). Comparing the effects in Columns (2) and (3), it is observed that the control variables reduce the coefficients' magnitude, indicating a considerable positive impact of housing prices driven by demand and city gentrification processes. However, despite controlling for as many variables as possible, the significant difference in coefficients suggests that any omitted variables not considered in the model would further decrease the magnitude. Hence, the effect presented in Column (3) can be considered an upper-bound effect of housing prices on the share of variety in the area.

TABLE 3 • OLS AND IV ESTIMATES - NUMBER OF TRADABLE PRODUCT SELLERS/ NON-TRADABLE SERVICE PROVIDERS VERSUS SALE PRICE CHANGES

	Tradable Sectors			Non-Tradable Sectors		
	(1) OLS	(2) IV	(3) IV	(4) OLS	(5) IV	(6) IV
log(Sale Price)	0.8216***	137.9139***	-5.0821**	0.0631	26.8976***	-5.6798***
	(0.2291)	(2.4078)	(2.4091)	(0.0787)	(0.7672)	(0.8445)
Sociodem. Control	Yes	No	Yes	Yes	No	Yes
Census 2011 Control	Yes	No	Yes	No	No	Yes
Buildings Control	Yes	No	Yes	No	No	Yes
Semester FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Semester*Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs.	61568	61568	61568	61568	61568	61568
Mean in 2019	55150	55150	55150	20031	20031	20031
1% Increase wrt Mean	0.15%	25.00%	0.92%	0.03%	13.42%	-2.83%

Notes: The Table reports the OLS and IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. Controls are grouped in i) Sociodem. Control includes the share of foreign residents, the share of young residents (0y-30y), the share of old residents (more than 66y), the log of population density, the log number of families; ii) Cesus 2011 Control includes the share of illiterates people in 2011, the share of people with a primary school licence in 2011, the share of people with secondary school license in 2011, the share of undergraduate people in 2011, the share of graduate people in 2011, and log of families in rent apartment in 2011; iii) Building Control includes the log number of residential buildings in 2011, log number of residential building construction in the 80s, log number of residential building construction in the 90s, log number of residential building construction in the 00s.

Table 3 illustrates the impact of sale prices on the number of tradable goods sellers (Columns 1-3) and non-tradable services providers (Columns 4-6). As in the previous table, both OLS and instrumental variable estimates are provided for each dependent variable. With regards to tradable goods sellers, the OLS result, Column (1), is biased due to endogeneity. However, the expected negative Direct Effect in Column (3) is significant. An increase of 1% in the sale price corresponds -0.92% variation in the number of tradable product sellers mean. Column (2) reports the *Direct* and *Indirect Effect* combined, although the coefficient is an upper bound due to omitted variable bias, as previously explained. Despite this, the effect is significant, with a substantial magnitude. A 1% increase in the sale price corresponds to a 25% variation in the average number of tradable product sellers. However, the comparison between Columns (2) and (3) indicates that the effect induced by demand changes is great and that the identified *Direct Effect* is likely an upper-bound effect.

The findings for non-tradable service providers are similar to those of tradable goods sellers. Endogenous issues persist in the OLS specification. However, the instrumental variable results demonstrate the effect on compliers. In the most rigorous specification (Column 6), the effect is negative and highly significant, resulting in a -2.83% change in the mean of the non-tradable sectors due to a 1% increase in housing prices. Conversely, the effect biased by demand is positive and significantly greater than zero in Column (5). A 1% increase in the sale price corresponds to a variation of around 13% in the mean number of tradable product sellers. The effect in non-tradable sectors appears to be smaller than in tradable sectors in Column (2), but the *Indirect Effect* has still a significant and high impact, moreover, the *Direct Effect* specification is likely to be an upper-bound effect.

The impact of different combinations of control variables on the results is presented in Tables A.4, A.5, and A.6. The findings suggest that the results are highly responsive to time-varying sociodemographic variables. However, introducing even a single additional variable leads to a significant reduction in the coefficients.

The analysis yields three primary findings. Firstly, real estate prices have a significant positive impact on product and service variety. Secondly, changes in housing prices elicit a similar negative response from both tradable goods sellers and non-tradable service providers. Lastly, the effect of gentrification on both sectors, tradable and non-tradable, is substantial.

6.3 Heterogeneous effect

The baseline results indicate a massive impact of housing price changes induced by the demand side. In this section, I explore how this effect varies across areas, specifically by examining the IV specification, Eq. 2, without control variables, which includes both the *Direct* and *Indirect Effect*. I focus on two vari- ables, the share of college-educated individuals and population density, as they are representative of both demographic and gentrification patterns in the city. I extracted their distribution per area in 2011 and subsampled the initial sample based on quartiles of each variable.

Since the level of education is a reasonable proxy for the level of income in that area, the first quar- tile of the share of college-educated individuals includes areas that were poorer in 2011, while the fourth quartile includes the richest ones. Table 4 in Panel A reports the results on the share of variety supplied in each area. The findings indicate that the increase in variety supplied due to an increase in sale price is much lower in the richest areas (see Columns 4 and 5), whereas the overall effect is driven by poorer areas (see Columns 2 and 3). For the tradable sectors, the effect is primarily driven by the second quartile, although it is also high for the first and third quartiles. In contrast, for non-tradable activities, the greatest effect is observed in the poorest areas of the city as the share of product/service variety. these results sug- gest that tradable and non-tradable activities are affected differently in different areas. Tradable sectors are highly influenced by housing prices in low and medium-income zones, whereas non-tradable services are primarily fostered in low-income zones. Notably, all specifications indicate highly significant coefficients.

Regarding the population density, the first quartile consists of sparsely populated areas in 2011, while the fourth quartile includes densely populated areas in the same year. Table 4 in Panel B shows that the sale price has a significant effect on the variety of local products and services in thinly populated areas. Similarly, the effect on tradable sectors is still stronger in the first quartile of the population distribution. However, non-tradable activities are highly impacted by sale prices in both the first and second quartiles, and the effect is negative in the last part of the distribution (see Column 5). Even in this setting, the results are significant, and there seems to be a difference in the impact between tradable and non-tradable activities, with the latter mostly affected in the first and second quartiles, while tradable sectors are affected only in the first quartile.

TABLE 4 • IV ESTIMATES - EFFECT OF THE SALE PRICES ON THE OUTCOMES

	Inp. Var: log(Sale Price)				
	(1)	(2)	(3)	(4)	(5)
Quartile	All	1^{st}	2^{nd}	3^{rd}	4^{th}
	Panel A Share College Student 2011 Distribution				
Dep var:					
Variety Share	2.4113***	3.9416***	3.8195***	1.5719***	0.3861***
Tradable	137.9139***	125.1159***	204.9355***	97.7083***	25.8370***
Non-Tradable	26.8976***	83.1140***	55.8328***	10.0060***	5.9010***
	Panel B: Population density Distribution				
Dep Var:					
Variety Share	2.4113***	1.5880***	0.8004***	0.5580***	0.1712***
Tradable	137.9139***	89.6540***	38.3452***	34.3494***	8.0171***
Non-Tradable	26.8976***	30.6740***	21.6251***	12.2073***	-9.0449***
N	61568	15392	15392	15392	15392

Notes: The Table reports the IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. All specifications do not include control variables. Fixed effects: semester, year, semester*year and neighborhhod.
Panel A subsamples the dataset following the distribution of the share of college students across areas in 2011. Panel B subsamples the dataset following the distribution of the population density across areas in 2011.

TABLE 5 • OLS ESTIMATES - (1) POPULATION DENSITY EFFECT ON THE SALE PRICES - (2) CROSS-SECTIONAL EFFECT OF THE SHARE OF COLLEGE PEOPLE ON THE HOUSE PRICE IN THE FIRST SEMESTER OF 2012

	(1)	(2)
	OlS - Panel	OLS - Cross-sectional
Pop. Density	165.3327***	
	(2.0916)	
Share Collage 2011		6.2893***
		(0.9224)
Semester FE	Yes	No
Year FE	Yes	No
Semester*Year FE	Yes	No
Neighborhood FE	Yes	No
Number of Obs.	61568	3848

Notes: The Table reports OLS specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. (1) The OLS applies to the whole panel dataset and shows a positive correlation between population density and sale prices. (2) The OLS applies just to the first semester of 2012 and shows a positive correlation between the share of college students and sale prices.

6.4 Mechanisms

In this section, I aim to examine possible demand channels that could account for the impact of housing prices on local economic activities. While (Stroebel and Vavra 2019) explore several mechanisms in their study, their research question differs from mine. Nevertheless, they identify several demographic and gentrification patterns that could result in shifts in population density, changes in population com- position, and changes in consumer behavior. In my study, I focus on analyzing the first two mechanisms. Unfortunately, I don't have sufficient data to examine changes in consumer behavior.

To investigate the possible mechanisms, Table 5 reports the results for two different exercises. In Column (1), I examine the correlation between population density and sale prices. The results indicate a high magnitude and a high degree of significance for the coefficient, supporting the idea that population density is a plausible mechanism through which demand could influence housing prices. In Column (2), I look at the correlation between the share of college students and housing prices. However, since I only have information on the education level for 2011, the coefficient reports the results of a cross-sectional OLS only considering the first semester of 2012. Nonetheless, the positive magnitude and significance of the coefficient suggest that differences in population composition could also be a mechanism affecting housing prices.

7. Conclusions and next steps

This project examines the impact of housing prices on local economic activity. Unlike previous research, which has mainly focused on a single retail market (grocery stores), this paper looks at the effect on the entire range of products supplied to consumers, retailers and services. The study specifically investigates the effects of real estate prices on both the variety of products and services offered and changes with sector composition, distinguishing between tradable and non-tradable. To establish causality, an instrumental variable approach is used, exploiting the unique features of Turin's "Teleriscaldamento" system. The empirical strategy allows identifying both *Direct Effect* of housing price changes and *Indirect Effect*, namely changes induced by either demand shifts or gentrification processes in general. The findings indicate that sale price changes, as *Direct Effect*, positively foster the variety of products/services supply. However, the effect is negative on tradable good sellers and non-tradable service providers. The results indicate that demographic and gentrification processes have a significant and positive impact on local economic activities in both cases. This impact is particularly strong in sparsely populated and economically poorer areas for tradable activities, while in areas with low to medium population density and low medium income, the effect is more pronounced. Moreover, I found that both population density and income composition mainly affect housing prices when evaluating the *Indirect Effect*.

Overall, the study's results provide insights into the role of neighborhood changes and their reshaping effect on cities, highlighting local benefits and costs that can influence policy development. Additionally, these findings contribute to the public debate surrounding gentrification processes, in cities and in the retail market, and the possible next steps to take.

There are still many tasks that need to be accomplished. Further research is required to explore these mechanisms, and several potential exercises exist for this purpose, though they may require additional data. In addition, the empirical analysis should be subject to further examination. While the instrumental variable used appears to be robust, conducting more balance tests could provide additional support. Although the instrumental variable used seems robust, conducting more balance tests could provide addi- tional support for the results. Notably, the OLS and IV specifications reveal a discrepancy, and identifying the compliers could help to further support the findings. Lastly, several robustness checks are required to ensure the reliability of the results.

8. References

Abadie A., Athey S., Imbens G.W. and Wooldridge J.M. (2023), *When Should You Adjust Standard Errors for Clustering?*, «The Quarterly Journal of Economics», 138, 1, pp. 1-35

Almagro M. and Dominguez-Iino T. (2022), *Location Sorting and Endogenous Amenities: Evidence from Amsterdam*, SSRN 4279562

Angrist J.D. and Pischke J.-S. (2009), *Mostly Harmless Econometrics: An Empiricist's Companion*, Princeton, Princeton University Press.

Baum-Snow N. and Hartley D. (2020), *Accounting for Central Neighborhood Change, 1980-2010*, «Journal of Urban Economics», 117, 103228.

Behrens K., Boualam B., Martin J. and Mayneris F. (2022), *Gentrification and Pioneer Businesses*, «Review of Economics and Statistics», pp. 1-45

Borraz F., Carozzi F., González-Pampillón N. and Zipitría L. (2021), *Local Retail Prices, Product Varieties and Neighborhood Change*

Brummet Q. and Reed D. (2019), *The Effects of Gentrification on the Well-being and Opportunity of Original Resident Adults and Children, (2019-07-16)*, FRB of Philadelphia Working Paper No. 19-30

Chapelle G. and Eyméoud J.B. (2022), *Can Big Data Increase Our Knowledge of Local Rental Markets? A Dataset on the Rental Sector in France*, «PloS one», 17, 1, e0260405

Couture V. (2013), V*aluing the Consumption Benefits of Urban Density*, Berkeley, University of California

Couture V. and Handbury J. (2020), *Urban Revival in America*, «Journal of Urban Economics», 119, 103267.

Davis D.R., Dingel J.I., Monras J. and Morales E. (2019), *How Segregated is Urban Consumption?*, «Journal of Political Economy», 127, 4, pp. 1684-1738

Ding L. and Hwang J. (2016), *The Consequences of Gentrification: A Focus on Residents' Financial Health in Philadelphia*, «Cityscape», 18, 3, pp. 27-56

Glaeser E.L., Kolko J. and Saiz A. (2001), *Consumer City*, «Journal of Economic Geography», 1, 1, pp. 27-50

Glaeser E.L., Luca M. and Moszkowski E. (2020), *Gentrification and Neighborhood Change: Evidence from Yelp, Technical report*, National Bureau of Economic Research.

– (2023), *Gentrification and Retail Churn: Theory and Evidence*, «Regional Science and Urban Economics», 100

Stroebel J. and Vavra J. (2019), *House Prices, Local Demand, and Retail Prices*, «Journal of Political Economy», 127, 3, pp. 1391-1436

Vigdor J.L. (2010), *Is Urban Decay Bad? Is Urban Revitalization Bad Too?*, «Journal of Urban Economics», 68, 3, pp. 277-289

Vigdor J.L., Massey D.S. and Rivlin A.M. (2002), *Does Gentrification Harm the Poor?*, Brookings-Wharton Papers on Urban Affairs, Brookings Institution Press, pp. 133-182

Appendix

FIGURE A.1 • NEWSPAPER ARTICLE PUBLISHED BY THE GUARDIAN ON 2 MAY 2019

Retail industry

This article is more than **3 years old**

Thousands of UK shops left empty as high street crisis deepens

Data suggests closures of banks, pubs, estate agents and fashion stores is biggest rise in five years

Sarah Butler
@whatbutlersaw
Thu 2 May 2019 14.42 BST

FIGURE A.2 • NEWSPAPER ARTICLE PUBLISHED BY LA REPUBBLICA ON 28 FEBRUARY 2023

MENU | CERCA la Repubblica ABBONATI GEDI SMILE | R | ACCEDI

Commercio, 100mila negozi chiusi negli ultimi 10 anni in Italia

di Caterina Maconi

Aumentano le aperture di ristoranti e alberghi, ma non riescono a compensare il deficit. Cresce la presenza straniera, sia come numero di imprese che di occupati

28 FEBBRAIO 2023 ALLE 12:50

1 MINUTI DI LETTURA

Translation: Commerce, 100,000 shops closed in the last 10 years in Italy.

FIGURE A.3 • NEWSPAPER ARTICLE PUBLISHED BY EL PAIS ON 10 FEBRUARY 2023

EL PAÍS Economía SUSCRÍBETE INICIAR SESIÓN

EMPRESAS >

El cierre de empresas en España en 2022 batió récords: 26.207 disoluciones, un 10% más

Las disoluciones mercantiles superaron la cota más alta alcanzada hasta la fecha, de 2013

Translation: Company closures in Spain in 2022 hit a record: 26,207 closures, a 10% more.

FIGURE A.1 • LIST OF LICENSE CATEGORIES IN THE DATASET

Category	Category
Animals Articles	Automatic Machines
Appliances and Electronics	Bar and Restaurants
Building Material	Candies
Children Articles	Clothing
Cosmetics and Perfumery	Coffee Pods
Extralimentary	Food
Fabrics and Rugs	Gift Articles
Flowers and Plants	Hairdressers and Beauticians
Fuels	Mixed
Furniture	Objects
Games	Second Hand
Hardware Store	Sport Articles
Health and Orthopedic Articles	Supermarkets
Home Articles	Newspapers
House and Person Hygiene Articles	Optics
Jewellery	Pharmacy and Herbalist Articles
Laundry	Photography
Libraries	Sexy Shop
Motor and Car	Spare Accessories
Musical Instruments	Stationery Articles
Tobacco	

TABLE A.2 • LIST OF COSTS AVOIDED WITH THE TLR

Cost	approx.
System installation	20000€/installation
Ordinary boiler maintenance	5000€/year
Reading and repairing the boiler	600€/year
Extraordinary interventions	depending on breakdowns
Fire prevention certification renewal	500€ every 5 years
Boiler renewal	

TABLE A.3 • DESCRIPTIVE STATISTICS PER CITY AREA

	All Tracks without Centro & Hill			Centro & Hill			All Tacks		
Share of graduate people in 2011	50896	.1285054	.1101622	10672	.2608681	.1596865	61568	.1514488	.1302394
Share of undergraduate people in 2011	50896	.2529958	.1199731	10672	.2343875	.1320833	61568	.2497703	.1223601
Share of people with secondary school license in 2011	50896	.2416164	.1232215	10672	.1479094	.1014285	61568	.2253735	.1248719
Share of people with a primary school licence in 2011	50896	.1339976	.0785082	10672	.0819234	.0702353	61568	.1249712	.0796161
Share of illiterates people in 2011	50896	.0067286	.0124406	10672	.0032928	.0121921	61568	.0061331	.0124658

TABLE A.4 • IV ESTIMATES - SHARE OF VARIETY VERSUS SALE PRICE CHANGES

	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV
log(Sale Price)	2.4113***	0.0817***	0.6174***	1.2946***	0.1357***
	(0.1292)	(0.0299)	(0.0375)	(0.0776)	(0.0340)
Sociodem. Control	No	Yes	No	No	Yes
Census 2011 Control	No	No	No	Yes	Yes
Buildings Control	No	No	Yes	No	Yes
Semester FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Semester*Year FE	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
Number of Obs.	61568	61568	61568	61568	61568

Notes: The Table reports the IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard er- rors, in parenthesis, are clustered at the level of IV's variation. Controls are grouped in i) Sociodem. Control includes the share of foreign residents, the share of young residents (0y-30y), the share of old residents (more than 66y), the log of population density, the log number of families, ii) Cesus 2011 Contr includes the share of illiterates people in 2011, the share of people with a primary school licence in 2011, the share of people with secondary school license in 2011, the share of undergraduate people in 2011, the share of graduate people in 2011, and log of families in rent apartment in 2011 iii) Building Control includes the log number of residential buildings in 2011, log number of residential building construction in the 80s, log number of residential building construction in the 90s, log number of residential building construction in the 00s.

TABLE A.5 • IV ESTIMATES - NUMBER OF TRADABLE PRODUCT SELLERS VERSUS SALE PRICE CHANGES

	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV
log(Sale Price)	137.9139^{***}	-6.7581^{***}	25.0513^{***}	69.4324^{***}	-5.0821^{**}
	(7.7028)	(2.1452)	(2.4078)	(4.6403)	(2.4091)
Sociodem. Control	No	Yes	No	No	Yes
Census 2011 Control	No	No	No	Yes	Yes
Buildings Control	No	No	Yes	No	Yes
Semester FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Semester*Year FE	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
Number of Obs.	61568	61568	61568	61568	61568

Notes: The Table reports the IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. Controls are grouped in i) Sociodem. Control includes the share of foreign residents, the share of young residents (0y-30y), the share of old residents (more than 66y), the log of population density, the log number of families, ii) Cesus 2011 Contr includes the share of illiterates people in 2011, the share of people with a primary school licence in 2011, the share of people with secondary school license in 2011, the share of undergraduate people in 2011, the share of graduate people in 2011, and log of families in rent apartment in 2011 iii) Building Control includes the log number of residential buildings in 2011, log number of residential building construction in the 80s, log number of residential building construction in the 90s, log number of residential building construction in the 00s.

TABLE A.6 • IV ESTIMATES - NUMBER OF NON-TRADABLE SERVICE PROVIDERS VERSUS SALE PRICE CHANGES

	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV
log(Sale Price)	26.8976***	-5.5159***	0.2429	11.6500***	-5.6798***
	(1.7547)	(0.7434)	(0.7672)	(1.1814)	(0.8445)
Sociodem. Control	No	Yes	No	No	Yes
Census 2011 Control	No	No	No	Yes	Yes
Buildings Control	No	No	Yes	No	Yes
Semester FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Semester*Year FE	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	Yes	Yes	Yes	Yes	Yes
Number of Obs.	61568	61568	61568	61568	61568

Notes: The Table reports the IV specifications. Significance is indicated by * p<0.1. ** p<0.05, and *** p<0.001. Standard errors, in parenthesis, are clustered at the level of IV's variation. Controls are grouped in i) Sociodem. Control includes the share of foreign residents, the share of young residents (0y-30y), the share of old residents (more than 66y), the log of population density, the log number of families; ii) Cesus 2011 Contr includes the share of illiterates people in 2011, the share of people with a primary school licence in 2011, the share of people with secondary school license in 2011, the share of undergraduate people in 2011, the share of graduate people in 2011, and log of families in rent apartment in 2011; iii) Building Control includes the log number of residential buildings in 2011, log number of residential building construction in the 80s, log number of residential building construction in the 90s, log number of residential building construction in the 00s.

Léa Bou Sleiman

Displacing Congestion: Evidence from Paris[1]

Abstract. This paper shows that road-closing policies may have adverse short-run effects on pollution by reallocating traffic toward more congested roads. I study the impact of the 2016 closure of the Voie Georges Pompidou, a one-way expressway crossing downtown Paris, on traffic and pollution dis- placement. To do so, I rely on a difference-in-difference strategy based on the direction and the timing of traffic, which I implement on detailed road-sensor data. I show that the closure lowered average speed by over 15% on two sets of substitute roads: central streets nearby and the already con- gested southern ring road. Using air quality data, I show that NO2 concentrations increased by 6% near the ring road and by 1.5% near local roads. The reduced-form results on traffic are quantitatively consistent with a calibrated model of shortest route choice, which allows me to recover the underlying rerouting patterns. Even though few displaced commuters diverted to the ring road, they triggered a massive pollution increase because of the U-shaped relationship between emissions and traffic speed. Overall, I estimate that up to 90% of the pollution cost was borne by lower-income residents around the ring road, who lived far away from the new amenity created by the closure and mostly outside the jurisdiction responsible for the closure decision. Finally, I study counterfactual closure scenarios to assess under which conditions those adverse effects could have been mitigated.

Keywords. Congestion, Air Pollution, Public Transportation, Route Choice

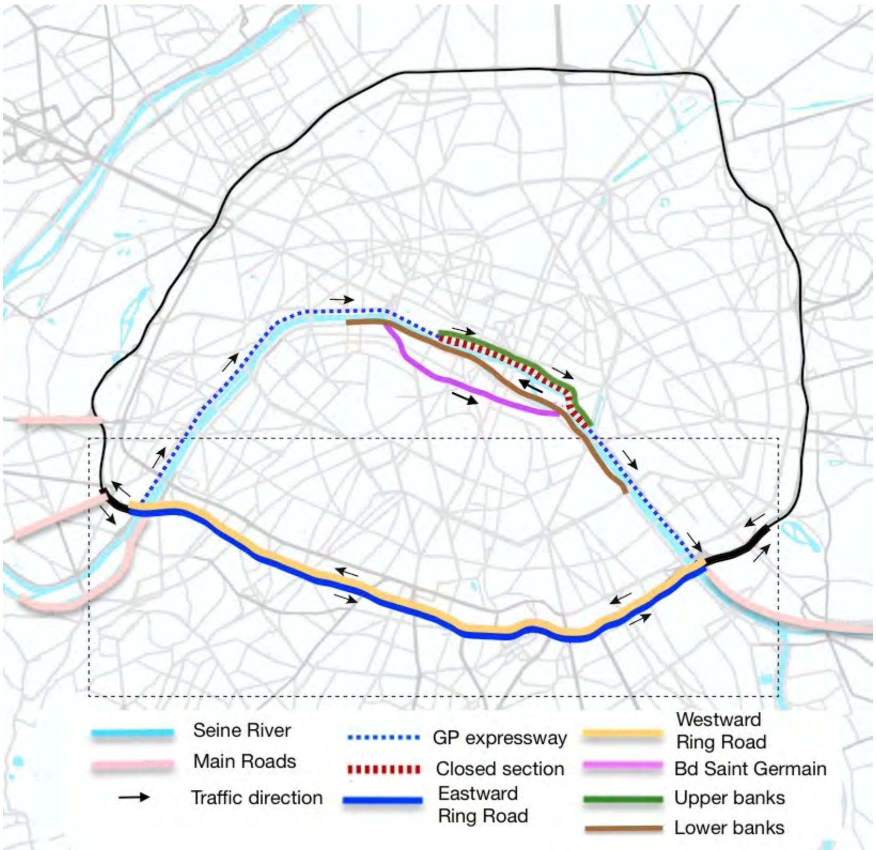
1. Introduction

Traffic congestion represents an undoubted threat to the quality of urban life, and keeping it under control has been an ongoing process (European Environmental Agency, 2020; WHO, 2005). In response, various traffic-calming policies have been used worldwide, some more readily received than others. Today, car-free streets have become the paradigm of contemporary

[1] I thank my committee members, Gilles Duranton, Benoit Schmutz, Pierre Boyer and Geoffrey Barrows for their support of this research. Thanks also to Julien Combe, Victor Couture, Patricia Crifo, Don Davis, Xavier D'Haultfoeuille, Paul Dutronc- Postel, Jessie Handbury, Mariaflavia Harari, Ben Keys, Jeffrey Lin, Isabelle Méjean, Roland Rathelot, Holger Sieg for their advice and input. Finally I appreciate the helpful feedback I have received from many seminar and conference participants as well as many PhD student from CREST and from the Real Estate Department of Wharton, University of Pennsylvania. I also thank the Paris City Council for sharing their data. This research is supported by several grants: LabEx Ecodec, the research initiative FDIR and EUR DATA EFM.

urbanism. Many cities in developed countries have started reducing their road supply to curb air pollution. Oftentimes, traffic is diverted to other roads, displacing congestion and pollution to other areas.[2] As such, even if the total number of commuters is reduced, the overall effect of road closures on the environment remains an open question due to the non-linear impact of traffic flow on emissions.

FIGURE 1 • THE EMPIRICAL SETTING: THE CASE OF PARIS



Notes: This figure represents a map of Paris. The dashed line represents the riverbank used by cars to cross Paris. The black line represents the limit of the city which corresponds to the ring road. I focus on the southern part of the ring roads, represented in the map by two thick lines. The thick section of the ring roads with an eastward flow direction corresponds to the south outer ring road. The thick section with a westward flow direction corresponds to the south inner ring road. The two local roads with an eastward flow direction represent the detour routes. The local road with a westward flow direction will serve as a control. The different main roads outside the city and leading to the GP are highlighted.

[2] https://www.nytimes.com/2022/09/12/nyregion/nyc-congestion-pricing-manhattan-bronx.html.

This paper provides quantitative evidence on the impacts of road closures in a city and the distribu- tional effects thereof. While the idea of road construction is well-established to be counter-productive as it may actually make congestion worse (Downs 1962; Duranton and Turner 2011), no study to this date has evaluated the impacts of road "destruction". I exploit a reform in Paris where a 3.3-km segment of the expressway along the Seine's right riverbank, the "Voie Georges Pompidou" (hereafter GP) got pedestrianized on September 1, 2016. The GP was the only expressway to cross the city. As shown in Figure 1, it was part of a 13-km road that crossed Paris from southwest to southeast. The closed segment was near Notre Dame Cathedral, the geographical and tourist center of the city. Until 2016, this road was used by approximately 40,000 vehicles every day. It was partly used for traveling within the city but also acted as a possible substitute for the ring road, especially its heavily congested southern section, for suburb-to-suburb traffic (Bouleau 2013). As such, the riverbank was part of a road network that was of general interest to the region.

First, I empirically estimate the impacts of this closure on substitute roads. A given road can be considered as a substitute if it is of almost same length and serves the same itinerary as the one considered (same starting point and exit point). The biggest challenges when evaluating a change in the road supply are accounting for (i) network effects (ii) simultaneity, and (iii) selection. These issues make it arduous to find the best setting in which the impact of a road closure on traffic can be causally identified and isolated from any other alteration in the city. This paper overcomes these challenges by implementing a difference-in-difference strategy based on the direction and the timing of traffic. To identify the effect of the pedestrianization, I make use of one particular feature of the GP: its unique flow direction. Given the unique flow direction of the GP, the direction of roads provides me with a natural selection of treatment and control groups: roads with the same flow direction as the riverbank are likely to be directly impacted by the GP closure by receiving a fraction of the displaced GP users. In contrast, the impact of the closure on the westward lanes, in the absence of alternative westward expressways within the city, may only have been indirect through a global decrease in traffic.

I also use the timing of traffic to ensure comparability between treatment and control groups, knowing that one direction is used in the morning and the other in the evening. In addition, each eastward substitute road has a similar westward road in the city with similar architecture (same type of steel and strip, presence or absence of traffic lights, outward/inward exit lanes). This makes it likely that traffic flows in either directions are independent. These different features allow for an evaluation of the GP closure by comparing its effect on the eastward roads to its effect on the westward roads in a difference-in-difference framework.

To measure traffic, I make use of the 2013-2019 road sensor data of the Paris City Hall. These data provide the occupancy rate (the percentage of time that vehicles occupy a given segment of the road) and the flow of vehicles, for every hour of the day. I also use a collection of dozens of road segments that match the substitute roads to the riverbank almost exhaustively. As shown in Figure 1, the GP expressway presents at least 3 itineraries of substitution, two of which are local roads with the same flow direction that circumvent the closed section: "Boulevard Saint Germain" and the upper banks. However, the third itinerary of substitution is the south outer ring road – serving as an alternative for the 13-km expressway road – forcing people to abandon the full riverbank.

In my main specification, I compare, before and after September 1st 2016, the occupancy rates and flow of cars of the roads with the same flow direction as the riverbank to roads with the opposite flow direction, controlling for segment and day×hour fixed effects. I run this estimate separately for local roads and ring roads since both sets of roads are likely to be impacted differently. The former will most possibly attract inner-city commuters while the latter will capture commuters intending to cut across Paris. Furthermore, they both have different technical road performances. While ring roads are made of continuous steel with no traffic lights or pedestrian crosswalks and a speed limit of 70km/h, local roads present several lights and pedestrian crossings with a speed limit of 50km/h at that time.[3] I first look at the impact of the GP closure on the two main outcomes: flow of cars and occupancy rates. I show that the flow of cars decreased by 6% on the ring road and increased by 26% on local roads. The difference in signs comes from the non-linear character of traffic flows since the same level of flow can be observed at two different speeds. For instance, a negative impact on traffic flows can indicate a decrease in the number of cars provided that the road is uncongested (at freeflow speed). It can also indicate an increase in the number of cars entering the road if downstream bottleneck is at capacity. In other words, a queue forms at the entrance of the road and grows with additional vehicles, which lowers the average speed on the road and decreases the number of cars counted in a given time span. To this matter, I turn my analysis to the impact on occupancy rates. I show that occupancy rates increased by 11.2% on the ring roads and by 34% on local roads, with the highest impact during evening hours. This is consistent with the fact that the GP expressway was mainly used during evening hours, since the west of Paris is an employment hub while the east of Paris is a highly-dense residential area.

I then look at congestion and average speed that I deduce using the occupancy rates and the flow of cars. I first compute an indicator of congestion by using the quadratic relationship between traffic flow and occupancy rate, described by the *fundamental diagram* well-known in the transportation literature. Second, relying on simple parametric assumptions, I can comment on the impact of the closure on the average speed of vehicles on the roads. I find that the ring roads are 21% more congested due to the GP closure while local ring roads show an increase in the probability of congestion of 50%. Both results are consistent with the conclusions I get from running the difference-in-difference on the average speed. Namely, I find a decrease in the average speed by 16.5% on the ring road and 17.5% on local roads.

I extend my work to the evaluation of the negative externalities of traffic. I make use of two permanent pollution monitors located near the periphery and near the upper banks. Using pre-closure data, I estimate the elasticity of NO_2 concentrations with respect to the average speed on nearby road segments, controlling for weather characteristics and the flow of cars. I multiply this elasticity by the impact on the average speed to impute the effect on NO_2 emissions, both near the upper banks and near the ring roads. With an elasticity of pollution to

[3] The speed limit on local roads was lowered to 30km/h citywide in 2022.

speed of -0.34% on the ring roads and -0.08% on local roads, I show that the emissions of nitrogen dioxide increased by 5.8% near the ring roads and by 1.5% near local roads. However, NO_2 emissions are not the only consequence of increased traffic. Increased noise pollution or other particulate pollutants can also occur. To have a sense of the magnitude of the overall cost, I evaluate the causal impact of the GP closure on housing prices near the periphery bearing in mind that all amenities are capitalized in housing prices. I find a decrease of housing prices in the 700-meter vicinity of the periphery by 5%.

Although we all experienced traffic congestion, the traffic problem is far from easy to understand. This is a consequence of the chaotic nature of traffic flows. A small input can get greatly magnified, which makes the problem "non-linear". In other words, a reallocation of cars from one road to a more congested road generates a net increase in congestion – and hence pollution. As such, it is impossible to back out the number of drivers switching on each substitute road just by looking at the reduced-form results. Yet, knowing the number of extra cars on each road is essential for the cost analysis. For this purpose, the second part of my paper provides a simple model of shortest route with endogenous congestion based on Akbar and Duranton (2017) to quantify the costs of the policy. The model predicts that the overall impact on congestion and pollution depends on the elasticity of congestion of each substitute road - i.e., the degree to which the number of cars impacts speed on the road. Closing a less congested road than its substitute roads will generate an overall rise in congestion and pollution in the absence of a (sufficient) mode switch. By estimating each treated road's congestion elasticity and distinguishing between (i) inner-city commuters and (ii) suburban commuters, I back out the number of commuters diverting on each road. This allows me to compute the costs generated and speak to the distributional aspects of this policy.

I show that higher-income commuters bear 60% of the time costs while lower-income residents bear 90% of the pollution costs, most of them living outside the local jurisdiction responsible for this closure. This brings into question the political economy behind the adoption of this kind of policy, which was implemented by the Mayor of Paris but ended up hurting people who live outside her jurisdiction. Finally, I use the model to study several counterfactual scenarios of interest from a theoretical or a policy point of view. They suggest that (i) closing only half of the segment would have drastically mitigated pollution externalities (ii) for the policy to yield zero pollution cost, more than 50% of inner-city commuters and 10% of suburban commuters should have had to switch to (uncongested) alternative transportation and (iii) a wider car-free zone (planned to take place by 2030) would lead to a slight decrease in pollution cost but a substantial increase in time cost, if no mode shift occurs.

Relation to the literature This project builds on and contributes to several literatures.

First, road reduction is part of a wide array of congestion policies implemented in cities, which have been studied in numerous works. On the demand-side, road pricing is seen as the most efficient and reasonable solution to deal with congestion (Liu and McDonald 1999; Santos *et al*. 2008; Tirachini and Hensher 2012; Winston and Langer 2006). However, with little social acceptance, many cities have instead used supply-side policies such as road space rationing, restricting the days or hours in which car users can drive on congested roads (de Grange and Troncoso 2011; Gallego *et al.* 2013; Kornhauser and Fehlig 2003) or urban rail-transit expansions (Adler and van Ommeren 2016; Gonzalez-Navarro and Turner 2018; Gu *et al.* 2021). Other cities, including Paris, have opted for quantity-rationing by gradually reducing their road capacity. For example, Seoul transformed its main highway into an urban boulevard (Kang and Cervero 2009) while New York has used High Occupancy Toll (HOT) lanes (Poole Jr and Orski 2000). In the case of Paris, the choice of road reduction rather than road pricing takes on a political dimension due to the low levels of consent to taxation among French car users.[4] This paper adds to this literature as it is, to the best of my knowledge, the first paper to causally identify the impacts of a road-reduction policy on traffic and congestion in a city.

Second, ever since the Downs (1962) paradox, a general consensus in the literature has emerged, whereby increasing the road supply is unlikely to reduce congestion: If you build it, they will come. This principle, known as the fundamental law of road congestion comes from the induced-demand. Although the elasticity of traffic to roadway lane kilometers is well-known to be close to 1 in the literature (Duranton and Turner 2011), no study to this date has sought to evaluate the symmetry of such elasticity. The question that arises here is whether reduced-demand reacts the same way: If you demolish it, will they not come? There are many reasons to believe this elasticity is not symmetrical. In fact, road expansion is implemented on heavily-used roads to relieve congestion, while road reduction is made to free up some high-amenity potential roads. In addition, road expansions lead to new home constructions next to a new highway or a major road, which would feed once again the induced demand. However, road reduction is unlikely to lead to homes being torn down.[5] I contribute to this literature by evaluating the short-run impacts of a road closure on traffic congestion. My results show that reducing the road capacity does not reduce congestion, at least in the short run.[6]

The only channel through which the demand might be reduced is through reallocation of residents or mode switch.

Third, this paper provides causal estimates of a marginal change in the road supply on both con- gestion and air pollution. On one hand, there is an extensive literature documenting the relationship between road restrictions and traffic congestion (de Grange and Troncoso 2011; Gallego *et al.* 2013; Kornhauser and Fehlig 2003). On the other hand, a large body of work in urban studies and transportation economics is devoted to the quantification of

[4] When President Macron made the decision to impose a gasoline tax, it backfired on him and the yellow vests (Gilets Jaunes) were quick to react and cause turmoil in the country (Boyer *et al.* 2020).

[5] The only channel through which the demand might be reduced is through reallocation of residents or mode switch.

[6] My results would have been comparable to a short-run evaluation of a road expansion. However, papers looking at road constructions focus on the long-run impacts with data less precise than the one I use. In this sense, I cannot really provide an elasticity of road kilometers to road traffic that would allow for a comparison between road expansion and road reduction.

the negative consequences of urban road traffic on health through pollutant emissions, although causal assessments are rather scarce (Anderson 2020; Currie and Walker 2011; Gibson and Carnovale 2015; Prud'homme *et al.* 2011). A common finding of many studies is that congestion policies may only have a positive impact on air quality if they do not increase congestion on untargeted roads (Bhalla *et al.* 2014). For example, Davis (2008) shows that banning some drivers from using their cars in Mexico City failed to decrease the use of car, thus providing no evidence that the restrictions have improved air quality. However, results have yet to be combined into a setting that evaluates the impacts of a traffic policy on both of these externalities.

Last, this paper contributes to the literature on the characterization of traffic congestion. Engineering studies find a convex relationship between traffic volume and travel time which suggests large marginal costs when congestion is already high. Economists have focused on two approaches to model congestion: the static speed-flow curve and the dynamic deterministic bottleneck model (See Small and Verhoef (2007) for a selected review of studies). Several papers have measured the effect of vehicle density on travel flows either on selected segments (Ardekani and Herman 1987; Geroliminis and Daganzo 2008) or for an entire city (Akbar and Duranton 2017). In this paper, I use the congestion model developed by Akbar and Duranton (2017) and extend it to the case of a road closure. By estimating the congestion elasticity of each treated road, I am able to predict the impacts of a road closure on substitute roads.

The reminder of the paper is structured as follows: Section 2 describes the background and data sources. Section 3 presents the main empirical analyses on traffic. Section 4 documents evidence of pollution increase. Section 5 sets up a theoretical model of pollution and congestion that I use to analyze the case of the GP closure, to quantify the costs of the policy and to report some policy counterfactual scenarios. Section 6 concludes by providing some policy insights.

2. Context and data

2.1 Commuting in Île-de-France and the riverbank shutdown of 2016

The Île-de-France region is in north-central France. It is divided into eight departments and surrounds Paris. In the Île-de-France region, job concentration follows a decreasing gradient, with Paris City as its core (see Figure G.1), consistent with the monocentric model (Chapelle *et al.* 2020).[7] Most individuals commute to the center of the region either by car or by public transportation, depending on access to train stations. Municipalities located in the east or west of Île-de-France have the highest share of car commuters (Figure G.2 (a)) and car use is particularly dominant for suburb-to-suburb journeys (Figure G.2 (b)).

[7] The resident gradient is reversed within Paris: densities are higher on the outskirts of the city, particularly around the ring roads.

The urge to transform the city into a greener one was at the heart of the 2014 municipal elections, won by Mayor Hidalgo.[8] Her campaign mainly focused on environmental and urban strategies that reversed previous schemes based on increasing road capacities.[9] Her program was threefold: offer a greater role to nature within Paris proper; promote the creation of public housing; and improve the efficiency of urban logistics. This included reducing the number of cars in the city by pedestrianizing some roads and creating new bus and cycling lanes.

The GP riverbank was the object of her most contested reform even though in the 2000s the progressive pedestrianization of the riverbank had already taken place. While banning cars from this road was initially implemented every Sunday and during bank holidays, then an entire month in summertime dedicated to "Paris Plage" (Paris-by-the-beach), Mayor Hidalgo formally established it on September 1st, 2016. This policy was justified with the urge to decrease vehicle circulation by provoking a mode shift, thus reduce pollution in the city when around 40,000 vehicles were circulating on this express-way every day. After the Paris Plage event of summer 2016, the GP riverbank from the Tuileries to the Henry IV tunnel was never reopened although the shutdown was not yet official. This project was first implemented in autumn 2016, but went through many protests and disputes before it legitimately took place. I provide a detailed description of the timeline implementation of this policy in Appendix A. Despite the struggles she had to face during her first term, Mayor Hidalgo was re-elected in 2020.

2.2 Data description

This study makes use of several databases:

Comptage routier - Données trafic issues des capteurs permanents. This is the main dataset for the study. The City Hall (Mairie de Paris) monitors the traffic situation on the main roads of Paris by implementing electromagnetic loops endowed with sensors in its pavements.[10] Roads are decomposed into segments or "arcs". Each arc is monitored by one sensor and corresponds to the unit of observation. The sensors can detect two main types of data:

- Occupancy rate: This corresponds to the time vehicles are located above a loop as a percentage of an hour. For example, an occupancy rate of 25% indicates that cars were present in the loop for 15 minutes.

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[8] Mayor Hidalgo has been the Mayor of Paris since 2014. She has been a member of the Socialist Party since 1994. Her political view is mainly centered around environmental policies. To fight air pollution, she introduced in 2016 a scheme called "*Paris Respire*", literally "Paris Breathes" by banning some cars from certain areas in Paris on the first Sunday of every month.

[9] For example, the riverbanks along the Seine river (dashed line of Figure 1) were first open to vehicle circulation in the 1970s with the aim of reducing travel time. This expressway was inaugurated in December 1967 by the Prime Minister Georges Pompidou. Originally, the project was meant to gather different sections in order to create a continuous fast track across the city.

[10] https://opendata.paris.fr/pages/home/

- Flow: This counts the number of cars that pass by a point in an hour. The same flow can correspond to either a saturated or a fluid traffic situation, depending on the corresponding occupancy rate level.

For each observation, I have hourly data of the occupancy rate and flow from 01/01/2013 00:00 until now. However, a public transportation strike happened in the last months of 2019 and the COVID-19 pandemic hit in 2020. Both events significantly impacted road traffic in Paris. To this matter, I restrict the dataset to observations until September 1, 2019.

I make use of these data to impute other variables which are important for my analysis. First, by assuming an average length of vehicles, I compute the average speed on each road section. I assume the average length of vehicles to be 4.5 meters.[11] Using the flow per lane as well as the occupancy rate, the average speed can be computed with Athol's formula (Hall, 1996):

$$Speed_{it} = Flow_{it} \times (L + K_i)/Occupancy_{it} \quad (1)$$

where $Speed_{it}$ represents the average speed (km/h) on road section i at time t, $Flow_{it}$ and $Occupancy_{it}$ are the flow per lane and the occupancy rate on section i at time t. L represents the average length of vehicles (here 0.0045 km) and K_i is the length in km of the road section i.[12]

Second, with flow and speed measurements, density (vehicles per kilometer) is easily calculated by dividing the flow rate by the speed:

$$N_{it} = \frac{Flow_{it}}{Speed_{it}} \quad (2)$$

$$N_{it} \approx \frac{Occupancy_{it}}{L + K_i} \quad (3)$$

with N_{it} representing the number of vehicles per kilometer on road section i at time t.

Unfortunately, these data are only available for Paris' roads which enables me to only observe the traffic impact on roads in intramural Paris. I also lack socioeconomic data regarding road users and cannot track vehicles due to the aggregated shape of the data. I use other datasets to ballpark aggregate consequences of the GP closure such as exposure to pollution or the impact on housing prices.

Population Census of 2013, 2014, 2015, 2016, 2017 and 2018 - Logements, individus, activité, mobil- ités scolaires et professionnelles, migrations résidentielles. For each individual, information about home location, workplace, mode of transportation, age, and status are available from censuses con- ducted by the National Institute of Statistics and Economic Studies

11 The length of vehicles passing can vary, especially when trucks are included in the sample. Therefore, the speed computed represents an approximation of the actual average speed.

12 Since the sensor occupies the entire road section, the length of each road section is equal to the length of the sensor.

(INSEE). This allows me to de- termine the percentage of people commuting by car and public transportation. However, these data provide no information on precise itineraries of commuters.

Pollution levels -Airparif. Airparif is a nonprofit organization, linked to the Ministry of Environ- ment, that monitors air quality in the Île-de-France region. Different monitors across the region register emission levels of various pollutants (NO_2, PM_{10}, $PM_{2,5}$ and O_3). I am interested in the monitors near the ring roads and the one near the upper banks. Both register hourly emission levels of NO_2 for the years 2013 to 2018, aiming at capturing pollution from traffic.

Public transport traffic per entry. Validations sur le réseau ferré: Nombre de validations par jour. Île-de-France mobilités[13] provides data on the daily number of people entering each train station. For this analysis, I use data on the two RERs (regional express networks), which are the main train lines serving Paris and its surrounding suburbs.

Demandes de Valeurs Foncières (DVF). I use exhaustive data recording all housing transactions in France from January 2014 to December 2018, recorded by the French Treasury for tax purposes in the DVF database. It provides information on the price of the transaction, its location, the date the transaction happened as well as some characteristics of the house (built area, number of rooms, type of house).

2.3 The Georges Pompidou riverbank

The *Georges Pompidou* riverbank is 13 kilometers long and crosses Paris from southwest to southeast (see Figure 1) with a unique flow direction (eastward). Figure G.3 provides some descriptive statistics of the riverbank traffic in 2015, a year before the pedestrianization of its center. The descriptive statistics of the pedestrianized segment (Figure G.3 (b)) suggest that this part of the riverbank is less congested or occupied than the average (lower flow and occupancy rate). In fact, the occupancy rate never exceeds 15%, which highlights the fluidity of the traffic on this segment. Furthermore, there is no obvious variability between peak hours and non peak hours. Instead, the flow of cars is always high from 8 AM to 9 PM. However, roads appear to be slightly more occupied during evening hours from 5 PM to 8 PM. This could imply that most users lived in the east and worked in the west.

In 2015, the average daily flow on the entire riverbank corresponds to 40,000 vehicles representing half of the daily flow of the south outer ring road. The 3.3 kilometers to be pedestrianized have a daily flow of around 35,000 cars. Although the shutdown was implemented on September 1st 2016, the pedestrianized area was already closed as of mid-July and throughout August for the *Paris Plage* event; hence, no traffic can be recorded during this period (Figure G.4). To obtain a sense of the impact of the closure on circulation, I plot the hourly mean of traffic flow of the riverbank when omitting the 3.3-kilometer stretch to be pedestrianized, be-

[13] *Île-de-France Mobilités* is the Organizing Authority for sustainable mobility in Île-de-France.

fore and after the closure (Figure G.5). The non- pedestrianized stretch of the riverbank presents a lower flow average after the shutdown, which pro- vides some suggestive evidence that some ex-riverbank users abandoned the whole riverbank itinerary once its center was closed. Indeed, former riverbank users could have either decided to change their means of transportation or to change itineraries. Had they decided to change routes, they could either circumvent the closed section using other local roads or abandon the whole riverbank and use another road. If so, a direct substitute would be the ring roads outside Paris. The eastward trip of the riverbank can be replaced by the south outer ring road.

2.4 The local roads

The closed section of the riverbank presents two clear substitutes roads within 1-kilometer: the *"Boulevard Saint Germain"* and the *upper banks*. Both substitute roads have the same flow direction as the riverbank. However, they both differ in two particular dimensions: (i) they are interrupted by traffic lights and pedestrian crosswalks, and (ii) they are equipped with cycling and/or bus lanes. These two features make them slower and subject to higher time variability than the riverbank. In Table F.1, I provide some descriptive statistics on both roads.

Descriptive data of the riverbank suggests that only a fraction of the riverbank users abandoned the itinerary and the larger fraction are still using the non-pedestrianized stretch (Figure G.5). Remaining users can only circumvent the closed section with local roads. In this paper, I estimate the impact of the GP closure on the substitute local roads within 1-kilometer of the closure.

2.5 The ring roads

Three main bypasses encircle Paris (Figure G.6) and allow travelers to circumvent Paris. The first one is the *Boulevard Périphérique* (Ring Road), which separates the municipality of Paris, over which the Mayor has jurisdiction, from the rest of the metropolitan area. The second circle represents the A86 highway, sometimes called the *Super Périphérique*. It forms a complete circle at a variable distance between 8 and 16 kilometers from the center of Paris in which suburb-to-suburb transit represents 87% of private vehicle commutes (Bouleau 2013). The third bypass is called *La Francilienne*, which is an incomplete set of highways and express roads circling the Île-de-France region; it is 160 kilometers long and approximately 30 kilometers away from the center of Paris.

In this paper, I evaluate the impact of the GP closure on the first bypass: *The Boulevard Périphérique*.[14] These ring roads are among the most commonly used urban roads of Europe. They are 35 kilometers long, which represents 20 times the length of the Champs-Elysées, and account for 2.5% of Paris' total linear roadway. Moreover, they take up to 40% of Paris' road traffic (Apur 2016). Suburb-to- suburb transit represents almost 40% of the traffic on these roads, compared to 55% for Paris-Suburb journeys (Bouleau 2013). I focus on its southern

[14] The Boulevard Périphérique is composed of one outer ring road an one inner ring road.

part since it represents a direct substitute to the riverbank (almost same length). It is of 10.5-kilometers and shares an entrance and exit with the GP expressway. Also, before the 2016 shutdown, using the ring road to cross Paris would deliver (almost) the same travel time as using the GP-expressway. In Table F.1, I provide descriptive statistics of the ring roads traffic before and after the riverbank shutdown. During daytime, we can note saturated traffic conditions even in the pre-shutdown period. As a result, adding extra vehicles to these roads is very likely to generate traffic jams.

3. Impact on traffic

In this section, I look at the impact of the GP shutdown on the traffic situation of substitute roads.

3.1 Empirical Strategy

3.1.1 Treatment and control groups

Using a difference-in-difference strategy, I evaluate the impact of the GP closure on traffic conditions of (i) local substitute roads, and (ii) the south ring road around the city. More precisely, I compare, before and after September 1st 2016, substitute roads with the same flow direction as the riverbank (treatment group) with similar roads of the opposite flow direction (control group). The main intuition behind my identification strategy stems from the idea that a GP-user is unlikely to divert to a westward road. In fact, since the GP has only one flow direction (eastward), ex-GP users are only impacted during the eastward trip of their commute. The westward trip is left unchanged, provided that they do not change means of transportation.

Since treatment and control groups must be comparable, I use the traffic on the same type of road with an opposite flow direction as a control for each treated road. First, I look at the impact of the riverbank closure on local substitute roads within 1-kilometer of the road closed, with the same flow direction as the riverbank and sharing and entrance and exit around the closed segment. This boils down to two treated roads: the *"Boulevard Saint Germain"* and the *upper banks*. I use the lower banks with the opposite flow direction as the control group. Indeed, the lower bank has the exact same characteristics as the treated local roads (i.e. speed limit, presence of traffic lights, number of lanes), with one main difference: an opposite flow direction. I select a road length of 6.6-kilometers of the control group to have the same number of road kilometers in the treatment and control groups. The treated local roads are composed of 44 arcs of roads and the control local road of 41 arcs of roads.[15]

I also look at the impacts on roads that could serve as a substitute to the entire GP expressway. As previously argued, the road along the Seine River was part of an itinerary for western-based commuters to access the eastern suburbs and vice versa. Given that the GP expressway was used

[15] The average length of a local road segment is of 0.14 kilometers.

by some commuters to cross Paris, it is likely that part of the effect was reflected on the ring road since it also serves this purpose. To this matter, I study the impact on the southern part of the *Boulevard Périphérique*. The treated road would be the south outer ring road since it is the eastern road of the south ring road. The control group is the south inner ring road, both roads being comparable: they are arguably the only akin roads that are completely independent of each other in the urban area, with one particular difference being the flow direction. The treated ring road is composed of 22 arcs of roads and the control ring road of 21 arcs of roads.[16]

3.1.2 Specifications

I first estimate the following specification over the period September 2013 - September 2019:

$$Y_{it} = \alpha + \gamma \mathbb{1}_{treated_i=1} \mathbb{1}_{post=1} + \lambda_t + \psi_i + \epsilon_{it} \tag{4}$$

where i represents the arc, a segment of a road, and *t* represents the time by the hour. Yit denotes the outcome considered on arc *i* at date *t*. The indicator variable $\mathbb{1}_{\text{treated}_i=1}$ equals 1 if arc *i* belongs to an eastward ring road (treatment group) and 0 if it belongs to a westward ring road (control group). The indicator variable $\mathbb{1}_{\text{post}=1}$ equals 1 if the reform has been adopted (after September 1, 2016) and 0 otherwise. ψ_i and λ_t are arcs and *day* × *hour* fixed effects, respectively. Standard errors are clustered at the arc level. Here, the causal inference I am interested in is captured by the coefficient γ. I expect this coefficient to be significant and have a positive sign on the occupancy rate if the policy displaces traffic to the substitute roads I restrict my analysis to.

I then estimate the following leads-and-lags regression to evaluate the impact of the policy several years after its implementation and test for the presence of pre-trends.

$$Y_{it} = \alpha + \sum \beta_k \mathbb{1}_{treated_i=1} \mathbb{1}_{T(t)=k} + \lambda_t + \psi_i + \epsilon_{it} \tag{5}$$

where *T(t)* represents the relative year compared to the year the GP riverbank was pedestrianized.[17] β_k represents the incremental impact of the policy on year *k*, compared to the reference year. All coefficient are normalized relative to year -1.

3.1.3 Identification: assumptions and threats

In the absence of treatment, the identification assumption claims that the difference between the treatment and control groups is constant over time. Here, it implies that absent from the September 2016 reform, the occupancy rates and flow of cars in the treatment and control groups would have evolved similarly. The trends of treatment and control groups are represent-

[16] The average length of a ring road segment is of 0.45 kilometers.

[17] A year includes the period from the 1st of September to the 31st of July of the following year, since August is omitted.

ed in Figure G.8, where the occupancy rates and flow of cars are represented by a yearly moving average. Control and treated units present, at least visually, parallel trends before 2016. In addition to graphical support, I test for the significance of the pre-treatment estimates. Figure 3 display the estimates of equation (5) and validates the presence of parallel trend. I portray below the three main threats to the identification strategy.

Credibility of control group. The main concern is the credibility of the control group. First, one might wonder whether the effects on the treated roads would spill over onto the non-treated roads. However, the control group has an opposite flow direction to the riverbank. Therefore, commuters are unlikely to substitute the riverbank itinerary with a road that has an opposite flow direction and eastward commuters would still keep the same path on their way back home (or westward commuters on their way to work). The only way the control group could have been impacted is through an overall decrease of traffic. If ex-GP users switch to alternative means of transportation, the control group would experience a decrease in the average traffic which would not be observed in the treated group. This would overestimate the impact of the GP closure. Second, the increase in traffic on substitute roads might have encourage some (non-GP) car users to shift away from car transportation. If it targets commuters who were initially on substitute road, the decrease in traffic would be similar in the treatment and control group; unless commuters do not use both sets of roads in their commuting trip. However, plotting the trend of the control group (Figure G.8) shows no clear decline in the occupancy rates over the years.

I make use of the timing of traffic to allow comparability between traffic in the control group and traffic in the treatment group for shorter time spans. Since commuters make use of one flow direction in the morning and its opposite in the evening, I use the evening traffic of westward roads as a control for morning traffic of eastward roads and vice-versa. This allows me to have approximately the same number of commuters in both groups when evaluating the impact of the GP on a subsample of hours. Appendix B discusses whether the GP closure provoked a mode switch towards public transporta- tion. I show that there is no significant evidence of an increase in the usage of the west-east public transportation lane. This results corroborates the idea that, at least in the short-run, the GP closure did not contribute to a mode switch among car-users.[18] In addition, the model developed in section 5 and calibrated on Paris is consistent with very limited mode shift.

Anticipation effects. The second worry boils down to anticipation effects: since the GP closure was announced in December 2015, commuters might have deviated from this itiner-

[18] Reluctance to switch transportation modes could have more than one explanation. The presence of subway congestion, especially during peak hours, increases the cost of shifting from car to public transportation (Haywood *et al.* 2018). It is also worth noting that individuals who purchased a car before 2016 may want to depreciate its cost over the years, so that any shift toward public transportation may only be visible over a longer time span.

ary before its official shutdown. Figure G.7 provides evidence of a potential anticipatory effect showing that people googled this event at the end of 2015. However, Figure 3 shows no significant difference between the treatment and control prior to 2016.

Other simultaneous urban policies. Finally, Mayor Hidalgo's first mandate was crammed with ur- ban modifications to promote alternatives to car. One of these was *Plan vélo 2015-2020*, which aimed for biking to represent 15% of the modal share of Paris and its nearby suburbs, versus 3% in 2014. If not taken into consideration, it could be responsible for part of the average treatment effect observed. However, this bias would exist if, for some reason, additional cycling and/or bus lanes were imple- mented on the eastward lanes differently than on the westward lanes. Other transportation programs such as new tramway lines were also implemented in recent years. To ensure that I disentangle the effect of the GP pedestrianization from these other programs, I perform a placebo test. I take a subsam- ple including all the observations before the event from January 1st, 2013 to August 31st, 2016. I then perform a difference-in-difference with phantom events (every 30 days starting January 1, 2015 until September 29, 2015). Figure G.9 represents the results of the placebo difference-in-differences. All the virtual treatment effects are statistically non-significant and close to zero, once again lending support to the identification strategy.

3.2 Main Results

In this section, I estimate the causal impact of the GP shutdown on the traffic situation of substitute roads. I first focus on the occupancy rate and flow of cars described in Section 2. Then, by imposing some assumptions, I look at the average speed and the probability of congestion. I separate the sample into three to capture time heterogeneity: morning hours (8Am to 10AM), evening hours (6Pm to 8PM) and daytime (8AM to 8PM). I estimate equations (4) and (5) to evaluate the average impact of the riverbank shutdown on the traffic situation of (i) local roads and (ii) the south ring roads.

3.2.1 Flow of cars

I first look at the impact on traffic flow. The flow of cars represent the number of cars that are counted in an hour on a given road segment. Table 1 gather the estimates of equation (4). The average flow during an hour increased by at least 26% on local roads. On the contrary, the number of cars passing during an hour decreased by 6% on the ring roads. The impact is consistent and significant over time (Figure 2). The difference in signs on both roads does not necessarily indicate that traffic has been displaced on local roads and not on the ring roads. In fact, a tiny disruption in the flow can cause congestion. In other words, traffic flow is linear, until it no longer is. The flow increases linearly as everyone continues to drive the posted speed limit and there are more cars on the road. However, as vehicles on the road increase to a congested state, they start to drive slower. Therefore, traffic flow does not behave linearly after some point.

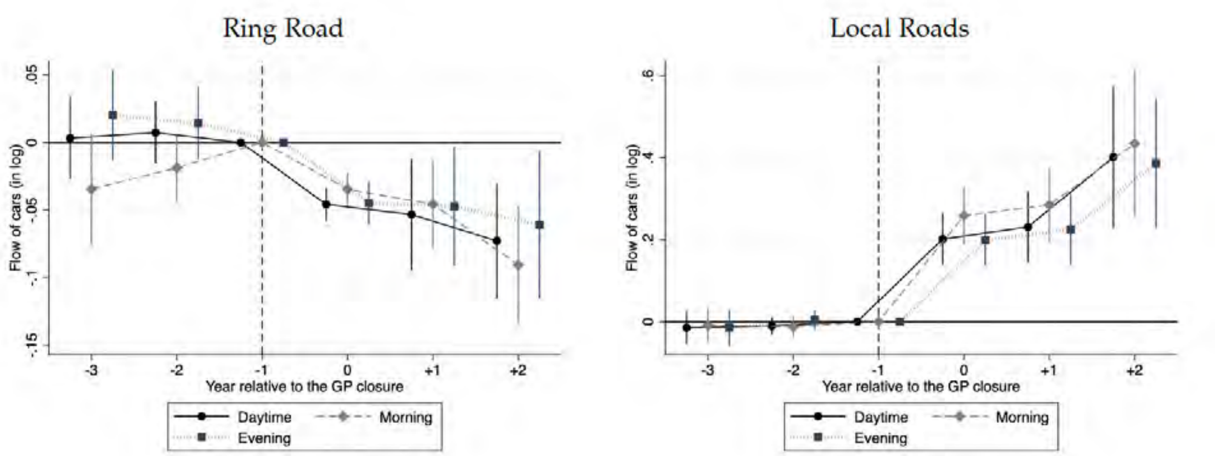
TABLE 1 • IMPACT ON THE FLOW OF CARS

	(1)	(2)	(3)
		Flow (in log)	
	Morning	Evening	Daytime
		Ring Roads	
Treatment	-0.061***	-0.081***	-0.061***
	(0.013)	(0.020)	(0.013)
Constant	8.387***	8.366***	8.395***
	(0.003)	(0.005)	(0.003)
Observations	14,4155	97,405	627,122
R^2	0.895	0.863	0.855
		Local Roads	
Treatment	0.331***	0.212***	0.264***
	(0.050)	(0.051)	(0.048)
Constant	7.125***	7.331***	7.189***
	(0.017)	(0.017)	(0.017)
Observations	335,934	227,045	1,461,499
R^2	0.797	0.712	0.750
Arc FE	Yes	Yes	Yes
Day × hour FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01
standard errors clustered at the arc level

Notes: The outcome is the log of the flow of cars in an hour. Column (1) represents the estimation during morning hours, from 8Am to 10 AM. Columns (2) during evening hours from 6PM to 8PM and column (3) during daytime from 8Am to 8PM. The first part of the table shows the impact on the ring roads. The second part of the table shows the impact on the 2 local roads considered: the boulevard saint germain and the upper bank.

FIGURE 2 • IMPACT ON THE FLOW OF CARS



Notes: These graphs plot the estimates and 95% confidence intervals from equation (5). The outcome is the log of the flow of cars in an hour: the count of cars that pass by a point in an hour. The straight line represents the estimates during daytime hours (from 8Am to 8PM). The dashed line represents the estimates during morning hours (from 8AM to 10AM) and the dotted line represents the estimates on evening hours (from 6PM to 8PM). All samples are restricted to the working days of the week (from Monday to Friday).

To understand what happens to the traffic situation on both roads, I then turn my analysis to the impact on the occupancy rates.

3.2.2 Occupancy rate

On the ring roads, the average impact is the highest for evening hours with an impact of 14.2% (com- pared to 9.4% for morning hours and 11.2% for the whole day). This is consistent with the traffic situation on the riverbank before its shutdown. Indeed, Figure G.3 shows that the riverbank was mostly taken during the evening, suggestive of a job/resident imbalance. However, the impacts on local roads do not vary much and remains around 33% (Table 2). Figure 3 shows the impacts over time and suggests higher occupancy rates even three years after the GP shutdown. A decrease in the magnitude of the impact is observed on the ring road for morning hours. However, the impacts across the years are not statistically different from each other during morning hours. The increase in the occupancy rates on both sets of roads suggests that treated roads are denser, which caused a decrease in the flow of cars on the ring road due to traffic jams.

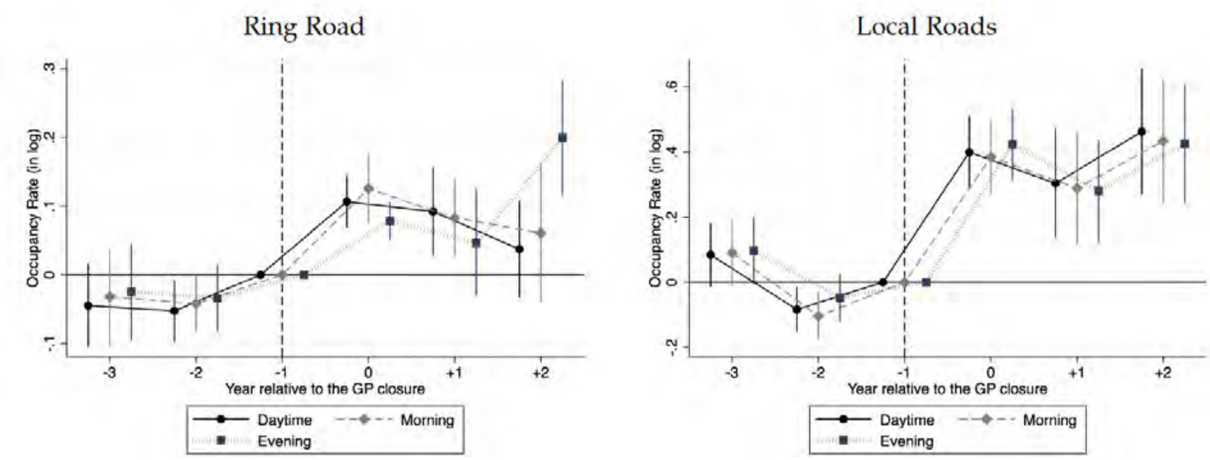
TABLE 2 • IMPACT ON THE OCCUPANCY RATE

	(1)	(2)	(3)
	Occupancy rate (in log)		
	Morning	Evening	Daytime
		Ring Roads	
Treatment	0.094***	0.142***	0.112***
	(0.017)	(0.026)	(0.018)
Constant	3.141***	3.264***	3.146***
	(0.004)	(0.007)	(0.005)
Observations	176,038	118,781	765,044
R^2	0.676	0.566	0.569
		Local Roads	
Treatment	0.321***	0.328***	0.339***
	(0.078)	(0.083)	(0.080)
Constant	2.158***	2.365***	2.233***
	(0.024)	(0.025)	(0.024)
Observations	397,931	268,689	1,729,726
R^2	0.613	0.580	0.579
Arc FE	Yes	Yes	Yes
Day × *hour* FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01
standard errors clustered at the arc level

Notes: The outcome is the log of the occupancy rate, which is a percentage of an hour. The occupancy rate represents the fraction of time a road section has been occupied by cars. Column (1) represents the estimation during morning hours, from 8Am to 10 AM. Columns (2) during evening hours from 6PM to 8PM and column (3) during daytime from 8Am to 8PM. The first part of the table shows the impact on the ring roads. The second part of the table shows the impact on the 2 local roads considered: the boulevard saint germain and the upper bank.

FIGURE 3 • IMPACT ON THE OCCUPANCY RATE



Notes: These graphs plot the estimates and 95% confidence intervals from equation (5). The outcome is the log of the occupancy rate: the percentage of an hour that vehicles stay on a loop. The straight line represents the estimates during daytime hours (from 8Am to 8PM). The dashed line represents the estimates during morning hours (from 8AM to 10AM) and the dotted line represents the estimates on evening hours (from 6PM to 8PM). All samples are restricted to the working days of the week (from Monday to Friday).

3.2.3 Robustness Checks

In what follows, I perform a number of checks and tests to validate the robustness of the previous results.

Fixed effects. I check that the result is not the spurious outcome resulting from a too saturated model. To this end, I first add the dummy variable $\mathbb{1}_{\text{treated}_i}=1$ to equation (4) and drop the arc fixed effects (Column (2) of Tables F.3 and F.4). The estimates for the treatment effect are barely affected and the significance remains the same. Second, instead of including time fixed effects that control for the differences between each hour of each day, I separately include year, month of the year, day of the week and hour of the day fixed effects. Column (3) of these same tables provide the estimates while changing the fixed effects. The inclusion of additive, instead of multiplicative time fixed effects decreases the R-squared but leaves the treatment effect virtually unaffected.

Clustering. Since road users are likely to drive on several sections of the same road, there might be reasons to believe that unobserved components of the traffic outcomes may be correlated between arcs of roads. For instance, we could think of accidents on a road that affect the occupancy rate of several sections of the same road. To address this concern, I construct clusters composed of arcs of road between two entries. Column (4) of Tables F.3 and F.4 show that the clustering at the road level increases the standard errors although the significance of the results remains unchanged.

Outliers. Some outliers can distort the outcomes and hence the estimates. We could think of two- wheelers exceeding the average speed of four-wheeled vehicles. This kind of behavior would appear at the bottom of the occupancy rate distribution. On the other hand, if a car stops on the road, say due to stalling, the sensor would register a very high occupancy rate on the relevant road sections. This would therefore appear on the top of the distribution. To take this into account, I winsorize the top and bottom of the occupancy rate and flow distribution at the 1% level. Results are shown in column (5) of Tables F.3 and F.4. The estimates and standard errors do not vary, which indicates that outliers do not drive the results.

3.2.4 Further Results

The results so far suggest that the riverbank shutdown is responsible for an increase in occupancy rates on the ring road as well as on 2 local roads within 1-kilometer of the riverbank. However, an increase in occupancy rates does not necessarily mean that the road is more congested or that the average speed on the road decreases. Indeed, consider a situation where only one car is on the road, driving at the speed limit. Adding another car on the same road will mechanically increase the occupancy rate. However, both cars can still drive at the speed limit, hence creating no traffic congestion. What matters on a broader economic scale is whether this policy is causing delays which result in the late arrival of workers. Since I cannot observe individually each commuter, I rely on the aggregated traffic data set to infer some conclusions about congestion and travel time. This section takes the analysis in this further direction by imposing stronger assumptions.

Probability of Congestion. As previously mentioned, the increase in occupancy rates is not a prob- lem per se. In fact, if the traffic is initially fluid, increasing the occupancy might not be harmful. The efficiency loss, if any, comes from congestion. To measure congestion, I make use of the fact that traf- fic flow per lane and occupancy rate are linked via a concave relationship known as the fundamental diagram in transportation economics (Immers and Logghe 2002). When a traffic situation is initially fluid, adding more vehicles on the road increases their present time by less than when the situation is already congested. For each arc of road, I estimate a quadratic approximation of the relationship between flow per lane and occupancy rate and compute the optimum *Occupancy**, above which a more occupied road is associated with a lower flow of cars. *Occupancy** is a road-specific indicator of hyper-congestion.[19] I create a dummy variable that takes the value 1 if the road is hyper-congested and 0 otherwise. I therefore estimate the impact of the 2016 riverbank closure on the probability of (hyper)congestion.[20] If the road's occupancy rates are close to the threshold prior to 2016, I expect the impact to be significant and positive. Table 3 suggests that the probability of congestion increased by 12 percentage point on ring roads during the day and 10 percentage points on local roads. Although both results are quite similar, they do not have the same impacts. In fact, the probability of congestion increased by 21.4% on the ring road compared to the pre-reform period and by 50% on local roads. Figure 4 shows that the impact on the probability of congestion is always positive during evening hours on both type of roads, even 2 years after the GP closure.

TABLE 3 • IMPACT ON THE PROBABILITY OF CONGESTION

	(1)	(2)	(3)
	Probability of Congestion		
	Morning	Evening	Daytime
		Ring Roads	
Treatment	0.106***	0.107***	0.119***
	(0.032)	(0.018)	(0.022)
Constant	0.359***	0.444***	0.421***
	(0.009)	(0.004)	(0.005)
Observations	120,788	204,004	627,123
Mean DepVar	0.307	0.570	0.557
R^2	0.363	0.366	0.372
		Local Roads	
Treatment	0.033	0.100***	0.101***
	((0.025)	(0.031)	(0.031)
Constant	0.053***	0.075***	0.079***
	(0.010)	(0.011)	(0.011)
Observations	292,243	474,426	1,461,657
Mean DepVar	0.069	0.196	0.202
R^2	0.242	0.239	0.284
Arc FE	Yes	Yes	Yes
Day × hour FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01
standard errors clustered at the arc level

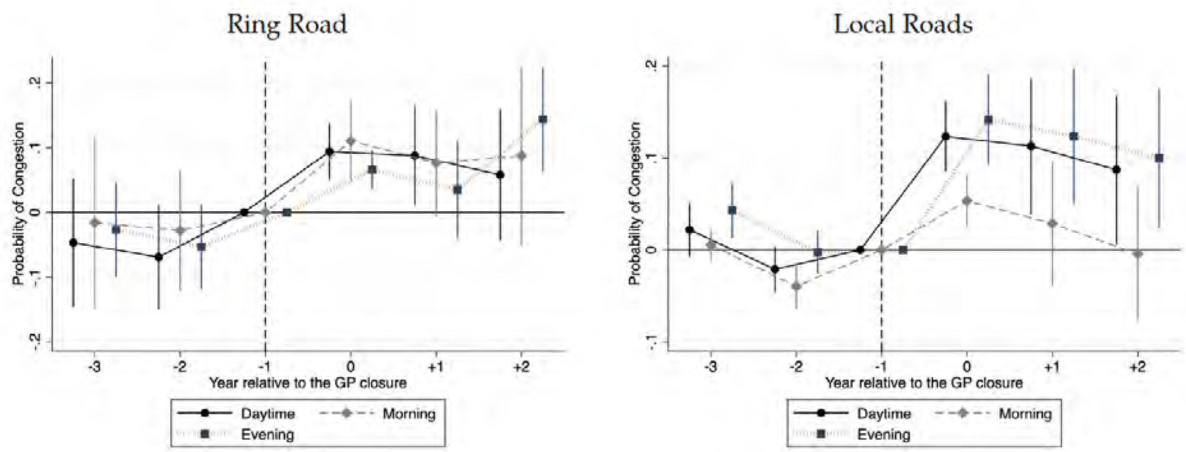
Notes: The outcome is a dummy variable that takes the value 1 if the occupancy rate is passed the threshold of the relevant road (Occupancy∗), and 0 otherwise. On average, it represents the probability of congestion. The mean of the dependent variable gives the average of the outcome variable in the treatment group during the pre-reform period. Column (1) represents the

[19] See Figure G.10 for an example.

[20] The outcome here is based on the estimated variable Occupancy∗. This might cause some measurement errors. However, as shown in Table 3, the coefficients are quite precisely estimated.

estimation during morning hours, from 8Am to 10 AM. Columns (2) during evening hours from 6PM to 8PM and column (3) during daytime from 8Am to 8PM. The first part of the table shows the impact on the ring roads. The second part of the table shows the impact on the 2 local roads considered: the boulevard saint germain and the upper bank.

FIGURE 4 • IMPACT ON THE PROBABILITY OF CONGESTION



Notes: These graphs plot the estimates and 95% confidence intervals from equation (5). The outcome is the probability of congestion. The straight line represents the estimates during daytime hours (from 8Am to 8PM). The dotted dashed line represents the estimates during morning hours (from 8AM to 10AM) and the dotted line represents the estimates on evening hours (from 6PM to 8PM). All samples are restricted to the working days of the week (from Monday to Friday).

Average Speed. I now turn my analysis to the impact on average speed. The results are in line with those of the occupancy rates (cf. Table 4). Namely, a decrease in the average speed is detected on the ring roads with the largest impact during the evening (21.6%). Average speed decreases by 16.5% during daytime for weekdays on the ring road and by 17.5% on local roads. Figure 5 plots the leads- and-lags regressions on the ring road as well as local roads. These results will allow me to compute the average time loss of commuters in section 5.3.

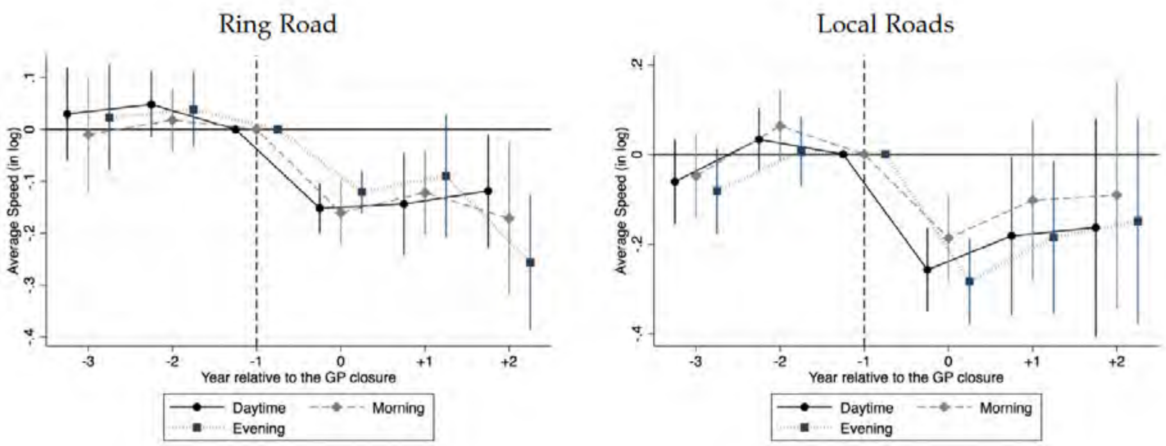
TABLE 4 • IMPACT ON THE AVERAGE SPEED

	(1)	(2)	(3)
	Average Speed (in log)		
	Morning	Evening	Daytime
		Ring Roads	
Treatment	-0.154***	-0.175***	-0.165***
	(0.032)	(0.033)	(0.029)
Constant	3.325***	3.220***	3.243***
	(0.009)	(0.008)	(0.007)
Observations	120,788	204,004	627,122
R^2	0.587	0.581	0.586
		Local Roads	
Treatment	-0.113	-0.170**	-0.175**
	(0.083)	(0.080)	(0.083)
Constant	2.421***	2.480***	2.420***
	(0.033)	(0.027)	(0.028)
Observations	292,214	474,261	1,461,407
R^2	0.698	0.665	0.692
Arc FE	Yes	Yes	Yes
Day × *hour* FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01
standard errors clustered at the arc level

Notes: The outcome is the log of the average speed in kn/h. Column (1) represents the estimation during morning hours, from 8Am to 10 AM. Columns (2) during evening hours from 6PM to 8PM and column (3) during daytime from 8Am to 8PM. The first part of the table shows the impact on the ring roads. The second part of the table shows the impact on the 2 local roads considered: the boulevard saint germain and the upper bank.

FIGURE 5 • IMPACT ON THE AVERAGE SPEED



Notes: These graphs plot the estimates and 95% confidence intervals from equation (5). The outcome is the log of the average speed on a road section. The straight line represents the estimates during daytime hours (from 8Am to 8PM). The dashed line represents the estimates during morning hours (from 8AM to 10AM) and the dotted line represents the estimates on evening hours (from 6PM to 8PM). All samples are restricted to the working days of the week (from Monday to Friday).

4. Beyond traffic: pollution and housing prices

The closure of the GP expressway caused an increase in congestion on substitute roads as seen in section 3.2. An increase in congestion – which translates into a progressive reduction in traffic speeds and an uninterrupted traffic flow – affects the air quality due to the slow downs and stop operations. The increase in pollution – if any – harms city-dwellers living near the substitute roads. In this section, I look at the impact of a decrease in the average speed on the road on the concentration of nitrogen dioxide: particles that primarily gets in the air from the burning of fuel.[21]

4.1 Empirical strategy

Ideally, I would want to study the causal impact of the riverbank shutdown on pollutant emission levels by comparing a set of pollution monitors near the ring roads with another set that is close to the unaffected roads, before and after September 1st, 2016. However, due to local dispersion of emissions, spillover effects would take place, which would prevent me from comparing the air quality near the treated roads to the air quality near the untreaded roads in a difference-in-difference framework. To this matter, instead of seeking to estimate the causal impact of the GP closure on pollution, I estimate the elasticity of nitrogen dioxide concentrations with respect to the average speed on nearby roads in the pre-shutdown period. Using this elasticity, I impute the impact on nitrogen dioxide using the result on speed shown in section 3.2.
I use two pollution monitors in Paris: the first one is located on the upper banks and the second one is located on the east ring road. I select the road sections near each monitor (see Figure G.11).[22] I restrict the sample to the pre-shutdown period and I estimate the following equation by assuming a log linear relationship between emissions and speed:[23]

[21] I focus on nitrogen dioxide since the concentration of this gas is particularly correlated with vehicle emissions (on the Health Effects of Traffic-Related Air Pollution 2010), while fine particles $PM_{2.5}$ are not affected by vehicle speed (Batterman *et al.* 2010). Also, exposures to NO_2 over short periods can lead to severe health issues since it can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2.

[22] In order to account for the same length of road near each monitor, I select 6 road sections on the upper banks and 1 road section of 800 meters on the ring road since the road sections of the upper banks are smaller in length. In total, each road selected represents approximately 800 meters.

[23] By plotting the average speed and pollutant concentrations, I find a decreasing relationship (Figure G.17). This negative correlation is already observed in other contexts (Pandian *et al.* 2009).

$$ln(NO_{2t}) = \alpha ln(Speed_t) + \theta Q_t + \zeta W_t' + \delta_{h(t)} + \delta_{m(t)} + \epsilon_t \tag{6}$$

where NO_{2t} is the nitrogen dioxide concentration at time *t*, Speedt is the average speed on the road section near the sensor at time *t*, Q_t is the flow of cars at time *t*, $\delta_h(t)$ is hour of the day fixed effects and $\delta_{m(t)}$ is month of the sample fixed effects. I also control for weather characteristics such as wind speed, wind direction or temperature represented by W_t'. The parameter of interest is α: the elasticity of nitrogen dioxide concentration to speed.

4.2 Results

The results of estimation (6) are represented in Table 5. The first column represents the naive regression with no time fixed effects. The elasticity would be biased if we consider that cars are less polluting with time. To this matter, I add month of the sample fixed effects to capture the time trend. The estimates are in column (2) and show that the order of magnitude and the significance of the results remain unchanged. Since speed is correlated with the hour of the day and emissions – conditional on the average speed – can vary across hours (for example because of heating, activities, trucks on the road), one might be tempted to add hour fixed effect. The estimate is represented in column (3). On the ring road, the magnitude of the estimate increases and the result remains significant at the 1% level. However, the elasticity of NO_2 with respect to speed using the monitor on the upperbanks becomes negative. Last, I add day of the week fixed effects to account for differences across the days of the week. The estimates are in column (4). The significance and sign do not change compared to the specification of column (3). My preferred specification is the one with month of sample and hour fixed effects (estimation of column (4)) since I make use of this elasticity to compute the average pollution cost across all days. On the ring roads, a decrease of speed by 1% increases air pollution by 0.35%. However, the impact is smaller on local roads, with an elasticity of 0.08%. The difference in the elasticities stems from the architecture of these two roads and the type of automobiles circulating on these roads. Indeed, the ring road is a freeway that does not have any traffic lights or pedestrian crosswalks. Hence, in the absence of congestion, the flow of cars would be uninterrupted and a decrease in the average speed is automatically attributed to an increase in congestion. On the contrary, automobiles driving on the upper banks are forced to stop due to the presence of traffic lights, regardless of the presence of congestion.

Imputation exercise. In all specifications the impact of the flow of cars on NO_2 emissions is negligible.[24] This said, I only use the elasticity of NO_2 to average speed to compute the impact of the GP closure on NO_2 concentrations. In order to do so, I extrapolate the elasticities found above to the context of the closure of the GP expressway. Recall that the GP shutdown caused a decrease in the average speed of 16.5% on the ring road and 17.5% on local roads during the day. Considering that the impact is linear and using the elasticities described above, I find an

[24] This is due to the fact that car flow is already present in the average speed.

increase of 5.8% in nitrogen dioxide concentrations near the periphery and an increase of 1.5% near the upper banks.[25] This increase in NO_2 comes on top of already high exposures, especially near the periphery (see Table F.5).[26]

TABLE 5 • ELASTICITY OF NITROGEN DIOXIDE WITH RESPECT TO THE AVERAGE SPEED

	(1)	(2)	(3)	(4)
	NO_2 emissions (in log)			
	Ring Roads			
Speed (in log)	-0.293***	-0.275***	-0.346***	-0.256***
	(0.019)	(0.018)	(0.021)	(0.022)
Flow (1000 v/h)	0.043***	0.034***	0.077***	0.073***
	(0.003)	(0.003)	(0.006)	(0.006)
Constant	6.053***	5.502***	5.579***	5.214***
	(0.100)	(0.100)	(0.104)	(0.108)
Observations	75,51	7,551	7,551	7,551
R^2	0.249	0.349	0.406	0.417
	Upperbanks			
Speed (in log)	0.062***	0.064***	-0.084***	-0.091***
	(0.023)	(0.022)	(0.020)	(0.020)
Flow (1000 v/h)	0.361***	0.367***	0.357***	0.290***
	(0.010)	(0.010)	(0.017)	(0.017)
Constant	5.440***	5.181***	5.376***	5.470***
	(0.076)	(0.079)	(0.069)	(0.068)
Observations	10,170	10,170	10,170	10,170
R^2	0.336	0.373	0.536	0.559
Weather Characteristics	Yes	Yes	Yes	Yes
Month of Sample FE	No	Yes	Yes	Yes
Hour FE	No	No	Yes	Yes
Day of the week FE	No	No	No	Yes

* p<.10, ** p<.05, *** p<.01

Notes: This table represents the elasticity of nitrogen dioxide emissions with respect to the average speed of vehicles on nearby roads. The first part of table represents the estimates of equation (6) on the ring road and the second part of the table the estimates on the upperbanks. The first column represents the naive regression without any time fixed effects. The second column adds month of the sample fixed effect to the regression. The third one adds hours fixed effects and the last column adds day of the week fixed effects. Since weather conditions are only registered every 3 hours, I only keep the traffic data of those hours in the sample. The flow of cars is normalized to 1000 vehicles per hour.

Other negative externalities. The increase in traffic does not only impact NO2 emissions. It also alters the level of noise pollution and other types of pollution. Due to data availability, I am unable to evaluate the general impact of an increase in congestion on negative externalities. In

[25] For the ring road: $-16.5 \times -0.35 = -5.775$. For local roads:: $-17.5 \times -0.084 = -1.47$.

[26] The European Union legislation states that the maximum acceptable level of NO_2 is fixed to 40 microgram per cubic meter (Lorente *et al.* 2019).

order to have a sense of the magnitude of this effect, I look at the impact of housing prices near the ring road. The motive behind this analysis stems from the principle that all externalities, if anticipated or well-perceived by residents, should be reflected in housing prices. The analysis is described in Appendix C and results suggest that transacted prices decreased by at least 5% within 700-meters of the south ring road. Sullivan (2016) finds that an increase in 1 $\mu g/m^3$ in NO_2 emissions is associated with a decrease in housing values by 0.7%. The average NO_2 level registered in 2015 near the ring road was of 67 $\mu g/m^3$ which implies that NO_2 increased by 3.8 $\mu g/m^3$ using 2015 as the reference year. In this sense, the impact on housing prices is much larger than the one reflected in the literature. This result implies that the road closure generated an increase in negative externalities beyond NO_2 emissions.

5. A model of route choice

The total cost of this policy can be reduced to (i) commuters' time losses and (ii) residents' exposure to higher pollution levels. If pollution is fixed in the short-run, reduced-form results on pollution along with an exogenous calibration are sufficient to compute the pollution costs.

On the contrary, computing the cost associated with the time loss is more complex. The reduced-form estimates measure the causal impacts of the GP closure on traffic on substitute roads. However, the non-linear relationship between flow and speed makes it impossible to assess the number of people shifting on substitute roads just by looking at the reduced-form results, which prevents me from com- puting the costs of the policy.

For this purpose, I build a traffic model inspired by Akbar and Duranton (2017). By distinguishing between inner-city and suburban commuters and residents, the model allows me to speak to the dis- tributional aspects of this policy. Finally, I make use of the model to study counterfactual scenarios.

5.1 A general framework

5.1.1 Set Up

The model follows the congestion model of Akbar and Duranton (2017), in which roads and route choices are modeled in a stylized model and congestion is endogenous. I extend this framework by adding two types of commuters, where each commuter chooses the fastest route.

In contrast to many of the papers in the transport literature, the model abstracts away from any mode switch, motivated by the public transport analysis in Appendix B suggesting that – at least in the short run – commuters do not rethink their transportation mode following a marginal change in the road supply. This assumption restricts the decision of commuters to their route choice. I also abstract from any job and home reallocation. Last, I abstract from any network effect.[27]

[27] One potential network effect that is not taken into account here is the decision of other commuters not directly impacted by the policy. For example, commuters initially present on the substitute roads.

The road system. Consider a city and its near suburbs composed of different neighborhoods $j \in J$, served by several roads $r \in R$ of direction $d(r)$. Each road r belongs to a road type $\mu(r) \in \{a,e,f\}$. Arterial roads (a) are high capacity roads that deliver traffic to and from centers of activity. I denote by n_a the number of arterial roads in the region considered. Freeways (f) are roads designed for fast moving vehicles to travel longer distances with high speeds (ring roads, highways…). I denote by n_f the number of freeways. Finally, expressways (e) are roads designed to travel quickly with great comfort and safety by avoiding sharp curves, busy traffic intersections or railway junctions. In this framework, I consider that the region has at most 1 expressway of each direction and each expressway crosses the city.

Residents. The region is populated with a continuum of agents of measure 1. Each individual suffers from the presence of cars on the roads through (i) travel time and (ii) air pollution. In fact, (non- commuter) residents suffer from the increase in commuters on nearby roads since it increases pollution. Car-commuters suffer from the increase in the number of travelers on the roads used to commute, since it triggers congestion. They also suffer from an increase of commuters on roads near their residential place. Therefore the marginal cost of additional cars on a set of road C are reflected in (i) the marginal pollution cost in the residential areas near roads $r \in C$, and (ii) the marginal increase in commuting time for car-commuters using any road $r \in C$.

Travel Time. Consider two types of commuters: (i) Inner city commuters denoted by I: commuters who live and work inside the limits of the city, and (ii) Suburban commuters denoted by O: commuters who live in the suburbs and work either in the suburbs or inside the city. The total number of commuters on each road r is $N_r = O_r + I_r$. Each commuter chooses a means of transportation $m \in$ {Car, Public Transportation}[28]. The travel time of a trip using a set of roads C ∈ R can be expressed as:[29]

$$\sum_{r \in C} T_{rt} = \sum_{r \in C} \frac{D_r}{S_{rt}(N_{rt})} \tag{7}$$

where $S_{rt}(N_r)$ is the average speed on route r at time t and D_r is the length in kilometer of road r.

I borrow the functional form of the average speed from the framework developed by Akbar and Duranton (2017):

$$S_{rt}(N_{rt}) = \overline{S_r} N_{rt}^{-\sigma_\mu(N_{rt})} \tag{8}$$

[28] The share of m from residence i to workplace j is considered fixed.

[29] The trip can either be done by using single-type roads, or the combination of arterial roads and expressway since both roads are inside the city. In the latter case, the travel time would be the weighted average speed of the trip over the total length of the roads.

where $\overline{Sr}$ is the theoretical maximal speed on road r, N_r the number of cars on road r and $\sigma\mu(N_{rt})$ is the elasticity of congestion on a road of type μ i.e. the degree to which the average speed on the road is impacted by the number of cars on that given road, with:

$$\sigma_\mu(N_r)\begin{cases}<1\ if\ N_r<N_r^{max}\\ >1\ if\ N_r>N_r^{max}\end{cases}$$

With a low car density, increasing the number of cars on a given road decreases less than pro- por- tionally the average speed. However, once the number of cars reaches a certain level, the decrease in the average speed becomes more than proportional, referring to a hyper-congested situation. This result is caused by the traffic demand greatly exceeding the traffic capacity, which cannot be relieved in time.

There are two extreme situations. The first one is when the elasticity of congestion is inelastic. In that case, the average speed on the road remains constant to the change in the car density. This can be observed at night when few cars are on the road. Increasing the demand marginally will not influence the average speed, especially in the absence of traffic lights. The second extreme case is an infinite elasticity of congestion. If the car density remains unchanged, the impact on the average speed will be infinite. This can be reached in the presence of high traffic volume, especially during peak hours.

Pollution. The presence of cars on the road increases air pollution through two channels: (i) the number of cars and (ii) the level of congestion. An increase in the number of cars mechanically generates an increase in emissions. If the increase in traffic is such that it provokes an increase in congestion, the average speed on the road decreases. As such, the average speed on the road is correlated with the level of pollutant emissions. However, the relationship is not linear. If the average speed on a given road is high, decreasing it might be a way to reduce emissions since it would decrease fuel consumption. However, reaching a certain speed level, lowering the average speed would increase the emission levels. This is because of the increased amount of acceleration and braking in stop-start driving, although these could be reduced if traffic flow was smoothed. The transportation and environmental literature well documents this relationship between emissions and average speed (Kean *et al.* 2003; Lozhkina and Lozhkin 2016). To this end, the level of pollutant emissions can be expressed as:

$$A_i(\mu(r'))=\begin{cases}S_{r'}(N_{r'})^{-\alpha_{\mu(r')}}\ if\ S_{r'}<\tilde{S_{r'}}\\ S_{r'}(N_{r'})^{\zeta_{\mu(r')}}\ if\ S_{r'}>\tilde{S_{r'}}\end{cases}\tag{9}$$

$\tilde{S_{r'}}$ is the threshold above which an increase in the average speed increases emissions, $\alpha_{\mu(r')}$ is the elasticity of pollution with respect to the speed whenever $S_{r'}<\tilde{S_{r'}}$ and $\zeta_{\mu(r')}$ the elasticity of pollution with respect to the speed whenever $S_{r'}>\tilde{S_{r'}}$.

5.1.2 Closing a fraction of the expressway

Consider a public reform where a fraction x of a road r of type $e(r)$ is permanently closed to increase the amenities in the vicinity of the closed section. Consequently, car commuters who used to take the expressway (N_e^{pre}) need to shift to other alternative roads.

Inner-city commuters. The closure of a fraction of the expressway forces expressway commuters to alter their itinerary. Inner-city commuters are forced to substitute the closed segment of the expressway with substitute arterial roads.[30] Let A be the set of arterial roads serving as substitutes to the closed expressway. The average speed on substitutes arterial roads $r \in A$ after the closure is:

$$S_{rt}^{post}(N_{rt}) = \overline{S_r}(N_{rt}^{post})^{-\sigma_{\mu(r)t}(N_{rt}^{post})} \tag{10}$$

where $N_r^{post} = \overline{N_r^{pre}} + \frac{I_e^{pre}}{n_{r\in A}}$, $\overline{N_r^{pre}}$ is the fixed number of commuters initially on road r independently of the expressway shutdown, I_e^{pre} is the number of inner-city commuters who used to take the closed expressway and $n_{r\in A}$ the number of arterial roads serving as substitutes roads. Here, the congestion elasticity on substitutes arterial roads is $\sigma_\mu(r)$ and depends on the technical characteristics of arterial roads, and the number of cars on the road.[31]

Suburban commuters. Once a fraction of the expressway is closed to car circulation, suburban com- muters are left with two choices: (i) take one of the alternative arterial roads inside the city (r $\in A$) once they get to the closed section, and (ii) abandon the expressway to the profit of a freeway at the periphery that can serve as a substitute: r′ $\in F$ with F the set of substitute freeways. A freeway is considered as a direct substitute if: (i) it is of almost the same length of the entire expressway, (ii) it shares an entrance and exit with the expressway and (iii) it has the same flow direction. If in the pre-shutdown period, using the mixed itinerary of expressway and local roads is faster than using an alternative freeway: $T_{r\in A} + \mathrm{T}_{e,non-closed} \leq T_{r\in F}$, a fraction β of the ex-expressway suburban commuters will reroute to the freeway and a fraction $1 - \beta$ will circumvent the closed section until travel times on both itineraries are equalized. The number of suburban commuters choosing to reroute is defined by the following post-shutdown equilibrium equation:[32]

$$\underbrace{(1-x)\overline{S_e}(\overline{N_e}+N_e-\beta O_e)^{-\sigma_e}}_{\text{Speed on the non-pedestrianized strech}} + \underbrace{x\overline{S_r}(\overline{N_r}+(1-\beta)\frac{O_e}{n_a}+\frac{I_e}{n_a})^{-\sigma_a}}_{\text{Speed on arterial roads with diverted inner-city and suburban commuters}} = \underbrace{\overline{S_{r'}}(\overline{N_{r'}}+\beta\frac{O_e}{n_f})^{-\sigma_f}}_{\text{Speed on the freeway with diverted suburban commuters}} \tag{11}$$

[30] Arterial roads are the only roads inside the city apart from the expressway.

[31] The congestion elasticity can be expressed as follow: $\frac{\partial S_{rt}}{\partial N_{rt}}\frac{N_{rt}}{S_{rt}} = \sigma_r(N_{rt})$

[32] The equation holds for any t, therefore I remove t for conveniance.

In that case, the freeway congestion elasticity does not only depend on the number of cars on that road but also on the congestion elasticity of local roads as well as the initial number of people on these roads. Hence, for every $r' \in F$ the congestion elasticity can be written as: $\frac{\partial S_r^f}{\partial N_r^f}\frac{N_r^f}{S_r^f} = \sigma_f(\sigma_a, \sigma_e, N_r, N_{r'})$. The pattern of commuter sorting therefore depends on several parameters like the number of alter- native substitute roads, the relative technical performance of roads and the initial conditions on each road, which are themselves conditioned by the city's architecture.

5.2 Model calibration: the case of Paris

I consider the case of Paris with 1 expressway (GP) of an eastern flow direction and of length normalized to 1 and one freeway of the same flow direction and of length 0.8, which represents the south outer ring road. The expressway was used by both inner-city commuters and suburban commuters to get from the south west of Paris to the south east. The lack of traffic lights and the fluidity of traffic make the expressway a convenient route to cross the city even for suburban commuters. In 2016, 25% of the expressway is pedestrianized at its center. Hence, all riverbank users are forced to alter their paths. In this set-up, there are 2 substitute arterial roads to the closed section and 1 substitute freeway to the entire expressway. Inner-city commuters will circumvent the closed section either by using the upper banks or the Boulevard Saint Germain. Suburban commuters, can either shift on the arterial roads previously mentioned or abandon the riverbank to the profit of the ring road.

5.2.1 Parameter estimation

There are three parameters to be estimated. The first one is σ, the elasticity of congestion. The second one is β, the fraction of suburban commuters switching on the ring road. Last, there is α, the elasticity of pollution with respect to the average speed on the road.

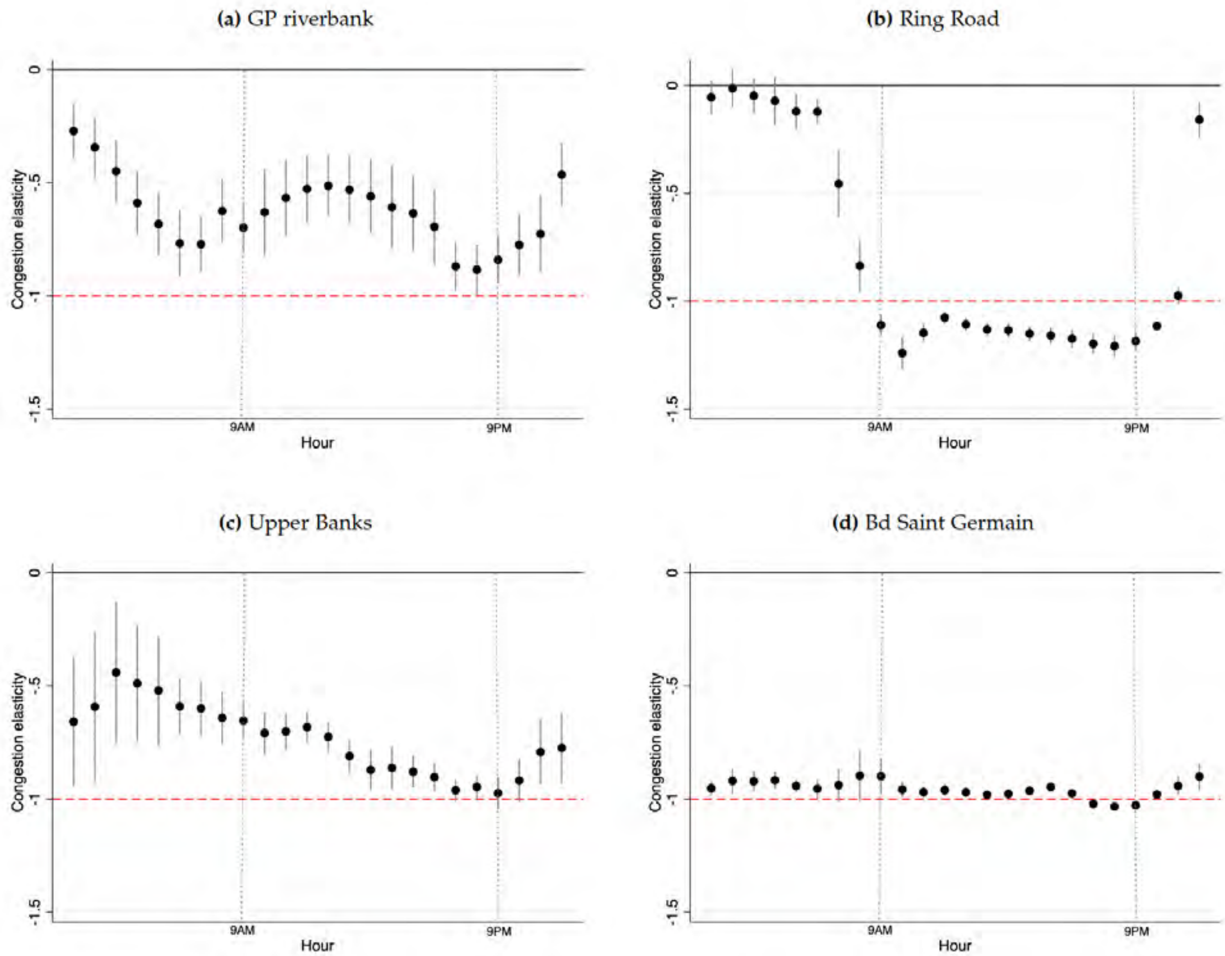
Estimating $\boldsymbol{\sigma}$. To estimate the congestion elasticities, I run the following regression for each treated road separately in the pre-shutdown period:

$$ln(S_{it}) = \alpha - \sigma_t ln(N_{it}) + \gamma_t + \gamma_i + \epsilon_{it} \tag{12}$$

where S_{it} is the average speed on road section i at time t, σ_t the elasticity of congestion (parameter of interest), Nit is the density of cars on road section i at time t, γ_t and γ_i are day of the sample and road section fixed effects respectively. Figure 6 shows the estimation of the elasticity of congestion for every road, by the hour of the day. The GP expressway presents an elasticity of congestion with little variability between the hours of the day. The elasticity of congestion is the closest to 0 during night hours, due to low traffic. No hypercongestion situation is noted here. However, the elasticity of congestion approaches 1 during evening hours.

The ring road presents an elasticity of congestion near 0 during night hours. However, for every hour during daytime, the ring road is hypercongested meaning that every extra vehicle on the road causes a decrease in the average speed that is more than proportional. While the upper bank shows an elasticity of congestion that decreases by the hour during the day reaching 1 at 9pm, the Boulevard Saint Germain presents almost no variability between the hours.[33]

FIGURE 6 • CONGESTION ELASTICITIES BY HOUR OF THE DAY



Notes: I plot the estimates of equation (12) by road and hour of the day. The estimates are represents with the black dot. The vertical lines represent the 95% confidence intervals.

Estimating β. β is the fraction of suburban commuters who abandon the expressway to the profit of the south ring road after the GP closure. In the pre-shutdown period, the number of cars using the GP expressway can be expressed as:

[33] The roads inside the city have non-zero elasticities of congestion during night hours since they are equipped with several traffic lights and pedestrian crosswalks, which causes a decrease in the average speed on the road independently of the number of cars passing by.

$$N_e = \underbrace{I_e}_{\text{Inner-city commuters using the expressway}} + \underbrace{\beta O_e}_{\text{Suburban commuters switching to the ring road}} + \underbrace{(1-\beta)O_e}_{\text{Suburban commuters switching to local routes}}$$

which are the inner-city commuters, the suburban commuters who will later reroute to the ring road and the suburban commuters who will choose to shift to arterial roads. One of the assumptions of the model consists in saying that car-commuters choose the fastest route. Table F.2 shows that before the GP closure, suburban commuters could cross Paris using either the expressway or the south outer ring road for almost the same journey time. Conversely, the mixed itinerary of expressway and local roads results in a longer travel time than the south outer ring road, regardless of the time of the day. Therefore, it is reasonable to consider that once the GP expressway is closed, all suburban commuters shift on the south outer ring road instead (β = 1). Since inner-city commuters use the GP to get from one point to another both inside the city, they are most likely going to shift to local arterial roads: upper banks and Boulevard Saint Germain.

Estimating α. Since I only have data on nitrogen dioxide emissions at the daily level, I restrict this elasticity to NO_2 emissions. The elasticity of NO_2 emissions to the average speed is estimated in section 4. I find an elasticity of -0.08% on local roads and -0.34% on the ring road.

5.2.2 Model predictions

Since only suburban commuters can shift on the freeway, every car abandoning the non-pedestrianized stretch of the expressway is a suburban commuter: $N^{pre}_{e,non-closed} - N^{post}_{e,non-closed} = \beta O_e$, with $\beta = 1$. Using the speed formula expressed in equation (8), I recover the speed impact by using (i) $N^{pre}_{e,non-closed} - N^{post}_{e,non-closed}$ as the number of suburban commuters, and (ii) the difference between the number of cars on the pedestrianized stretch before its shutdown and the number of suburban commuters: $N^{pre}_{e,closed} - O_e$ as the number of inner-city commuters who will shift to local roads. Using the estimated congestion elasticities, I recover the speed impact from the model γ_{model} displayed in Figure G.22.[34]

Results show that the speed impacts recovered from the model are closed to and lie in the confidence interval of the reduced-form estimates, suggesting that the model predicts accurately the impacts of the policy. Furthermore, the results predicted from the model suggest

[34] From Table F.1, I recover the average car density O_e and $N^{pre}_{e,non-closed} - N^{post}_{e,non-closed}$. O_e is the number of suburban commuters shifting to the ring road. I multiply this number by 2.4 since the GP has on average 2.4 lanes in order to have the number of cars on the entire road. I then divide the latter number by 3.3, since the ring road has 3.3 lanes on average and commuters will spread on all lanes. For inner-city commuters, I first multiply $N^{pre}_{e,non-closed} - N^{post}_{e,non-closed}$ by 2 since the closed GP has 2 lanes. I then divide the latter number by 6 since inner-city commuters will shift to 2 local roads, each of them having 3 lanes.

that there was no significant mode switch away from car use. Indeed, if some commuters had dropped their car due to the increased level of congestion, the results generated from the model would have been larger than the ones obtained with the reduced-form.[35]

5.3 Cost analysis

In this section, I first quantify the costs of the 3.3-kilometer closure in Paris. Then, I compute the costs of several counterfactual scenarios.

5.3.1 The costs of the 2016 GP closure

The pedestrianized section of the GP riverbank received 1.5 million visitors in 18 months, which the Mayor refers to as a "popular infatuation".[36] This high number of visitors reflects the highly-valued amenities derived from this closed section. However, the absence of additional data such as con- sumption, commercial rents, or the impossibility of determining whether these visitors are residents or tourists complicates the quantification of the benefits.

To this matter, I focus on the quantification of the costs of this road closure, reduced to the time loss and the increased pollution. This number can be therefore used by policy-makers to assess whether this type of policy makes sense according to the amenities that are anticipated. The description of the cost computation is described in Appendix D.

Pollution costs. The GP closure is responsible for an increase in pollutant emissions near substitute roads. Exposure to worsen air quality has adverse effects on human health.[37] Mink (2022) quantifies the health costs associated with an increase in NO_2 emissions in French urban areas. The rise in pollution near the local roads accounts for an annual cost of 950k €. The cost associated with the increase in pollution near the ring road is seven times higher, representing an annual cost of 7.2M €. The difference in costs stems from (i) the difference in the impact on pollution and (ii) the difference in the number of people impacted by the increase in emissions.

One limitation of this analysis is that I assume that the area of residence corresponds to the location of exposure to pollution. However, individuals could also be exposed to air pollution at their work location, during their leisure time and also while commuting. In addition, if they also spend some time on the closed section of the GP, they might be exposed to better air quality. In this paper, I abstract from these effects.

Travel time costs. Two categories of commuters are suffering from an increase in travel time after the GP closure. First, the direct losers of this policy are the ex-GP commuters. Suburban

[35] In the model, I make the assumption that individuals can only change their behavior at the intensive margin. Hence, I assume that every individual on the riverbank was displaced on another substitute road.

[36] https://www.lepoint.fr/societe/berges-de-seine-rive-droite-la-mairie-de-paris-affiche-son-succes-19-03-2018-220375023.php#11.

[37] In 2016, air pollution was estimated to play a part in 7.6% of worldwide deaths (WHO 2017).

commuters initially using the riverbank shift on the south ring road, which experienced a decrease in the average speed. 6,500 commuters per day lose 4 minutes, representing a value of 1.5M e to the economy. Inner- city commuters circumvent the closed stretch with local roads, contributing to the decrease of the average speed on these roads. Hence, 20,700 commuters loose 13 minutes, associated with a cost of 15.4M €.[38] Second, indirect losers are drivers initially on the substitute roads and now bearing the cost of extra users. The 40,700 drivers initially on local roads lose 2.6 minutes, which corresponds to an annual cost of 6.05M e and the 60,790 drivers initially on the south outer ring road lose 4 minutes, representing a cost of 14M €. The total time cost generated by the GP closure amounts to 37M €.

Benefits expected to exceed the costs. With a total annual cost of 44M €, I can compute the amount that each visitor should spend on the pedestrianized GP such that it compensates for the costs of the policy. Knowing that 1.5M people visited the closed GP in 18 months, I consider that the GP received 1M visitors in a year. This means that each visitor should spend at least 44 €.

Distributional impacts. While the benefits of pedestrianizing the riverbank are concentrated in the heart of the city, the costs are more spread out and impact two main groups of people: (i) Parisians and (ii) suburbans. The center of Paris is populated mostly by high-income residents. On the contrary, the peripheral area is inhabited by low-income residents (Figure G.21).

Being closer to the GP, residents living in Paris are more likely to benefit from the pedestrianization of the riverbank. Yet, they are not immune to the costs associated with this policy. Some inner-city car-commuters face an increase in travel time, and residents living near the local substitute roads (Bd Saint Germain and the upper banks) suffer from a deterioration in air quality.

Provided that all cars on the local roads are inner-city commuters while 5% of the commuters on the ring roads are Parisians (Apur 2016), the total time costs incurred by high-income residents is of 22.15M e, which represents 60% of the time costs.[39] Regarding the pollution cost, all residents near the local roads are considered high-income residents. They bear the 950k e cost of extra emissions gener- ated by the additional traffic on each road, which represents 10% of the pollution cost. All residents living near the periphery - on both sides - suffer from higher levels of air pollution representing an annual cost of 7.2M €, 90% of the pollution cost.

The high level of cost incurred by low-income residents mainly comes from the pollution they have to bear near the periphery. This is caused by 25% of ex-GP commuters who now use the south ring road and still cause 90% of the pollution costs. Therefore, one way of avoiding these large costs is to close the riverbank such as suburban commuters choose to use local routes

[38] Subtracting from the flow of cars on the pedestrianized stretch the number of cars shifting on the ring road, we get that 1,594 individuals per hour shifted on local roads (cf. Table F.1).

[39] I suppose that the time cost is constant and not proportional to income. However, one can consider that higher-income commuters have a higher cost time cost which would increase the gap between the time costs of higher-income and lower-income commuters.

instead of the south ring road. The shift of suburban commuters to the ring road happens at 2.6-kilometers of GP closure.[40] Below 2.6-kilometers of pedestrianization, suburban commuters prefer to shift to local roads as it would deliver a lower travel time.

5.4 Counterfactual scenarios

Recall that there are three main variables that define the number of road substitutes to a closed road. The first variable is the flow direction. To be considered as an alternative road, it has to be of the same flow direction to allow commuters to get to the same destination. The second variable is the entrance point of the closed road segment. Substitute roads should be reachable before or at the start of the closed segment. The third variable is the length of the closed segment. Direct substitute roads need to be of similar length. In this section, I make use of the theoretical framework to generate counterfactual situations. In each situation, the number of alternative roads and the number of commuters on each road deviates from the current situation.

Optimal closure under no mode switch. Here, I consider a counterfactual situation where the closed road segment varies. The starting point of the segment pedestrianized is fixed and the length of the road closed varies. Four cases can be identified in Figure G.23. Computation details can be found in Appendix E.

The first one is when the closed segment is less than 2.6-kilometers. I have shown that below 2.6-kilometers, suburban commuters switch to local roads along with inner-city commuters. However, if the segment closed is below 3.3-kilometers, Boulevard Saint Germain does not belong to the set of substitute arterial roads since it only shares one exit with the GP, after 3.3-kilometers of closure. Since the GP is the fastest route, commuters use it as much as they are able to. Hence, every commuter on the GP goes on the upper banks. In that case, the time cost is a linear function of the closed segment and the larger the closed segment the higher the time cost. The consequences are concentrated in the center of the city and residents near the ring roads are left untouched. Low-income commuters are only impacted through the time loss of ex-GP suburban commuters.

The second case refers to the situation where the closed segment is between 2.6 and 3.3 kilometers. At 2.6-kilometers, suburban commuters choose the ring road instead of local roads and inner-city com- muters choose the upper banks. This decreases the time cost for inner-city commuters and increases the time cost for suburban commuters. The time cost keeps on increasing until it reaches 3.3-kilometers.

However, the pollution cost increases drastically as the highly dense area of the south of Paris now suffers from increased pollution.

The third case represents the current situation. Boulevard Saint Germain is now a plausible substitute along with the upper banks. Therefore, adding another local road as an alternative, decreases the travel time for inner-city commuters. The pollution cost at the center increases linearly since more municipalities are impacted, while it is left unchanged near the ring road.

[40] Computations are found in Appendix D.

Last, above 3.3-kilometers, the upperbanks remain a local substitute road on the whole pedestrian- ized stretch since it is reachable anywhere from the GP. However, since the Boulevard Saint Germain only has one entrance and exit, it can only serve as a substitute for 3.5-kilometers. After that, all inner-city commuters shift back on the upperbanks.

One can notice in Figure G.23 that closing 1.8-kilometers instead of 3.3 would avoid the entire pollution cost borne by low-income people while keeping the time cost unchanged. Therefore, 1.8- kilometers corresponds to the larger distance that can be pedestrianized without impacting low-income residents that were not using the GP. This counterfactual scenario is interesting from a theoretical point of view. The set of alternatives is divided by three but the distribution of commuters remains the same, and yet the pollution costs are drastically mitigated.

Minimal mode switch for zero net pollution costs. One of this policy's goals was to shift away from private motorization. Although the model shows no room for traffic evaporation, one might wonder how many commuters need to drop their car so that the causal impact on traffic (and therefore on pollution) becomes null. There are two potential scenarios. The first one consists of having all commuters on local roads to avoid displacing externalities to the periphery. In this case, I compute the average speed needed in order for suburban commuters to stay on local roads. Computation details can be found in Appendix E. An average speed of at least 35km/h is needed for suburban commuters to choose this itinerary instead of the periphery. However, even at night where congestion is absent, the average speed is almost three times lower due to the road's performance. Therefore, the scenario of having everyone on local roads must be dropped.

This brings me to the second possible scenario: suburban commuters on the ring road and inner-city commuters on local roads, which corresponds to the current situation. In that case, the number of commuters that should drop their car in order to return to the initial level of commuters on each road corresponds to the number of additional commuters on each road. This means that 10.5% of commuters on the south ring road at 51% of commuters on the local substitute roads. In that case, pollution costs drops to 0 and time costs only account for the time loss of ex-GP users since the average speed on each substitute road is unchanged. This scenario is interesting from a policy point of view. In fact, by offering credible alternatives to car, the city might be able to generate zero marginal costs and still create positive amenities in the city.

Potential impacts of a wider car-free area. I turn to a counterfactual situation where commuting by car is banned in the center of the city.[41] This situation is already planned to take place by 2030, following the 2015 COP21 agreements. It has sparked some debates in the region with the opponents raising the point that suburban commuters might be penalized. If this situation takes place, the upper banks no longer belong to the set of substitute roads since they are located in the car-free zone. Boulevard Saint Germain becomes the only route on which commuters can switch to. Density of cars increases by 34%, decreasing speed by 33.7% on that road. This leads to a time cost of 60.5M € and a pollution cost of 7M €. Since pollution increased on one local road, a lower number of inner-city residents are impacted by the nearby increase of pollution while the same number of individuals are impacted by the increase in pollution near the periphery. This leads to a slight decrease

[41] The center of the city is considered to be represented by the following arrondissements: 1,2,3 and 4.

in the pollution cost since most of the pollution cost is borne by suburbans. However, the time cost increases substantially. Here, I consider that the number of car-commuters is constant. In reality, the number of car-commuters might decrease by 2030 following the pedestrianization of the center, especially among inner-city commuters who can easily refer to alternative means to car transportation.

6. Policy recommendation

It is quite challenging to find an environmental policy that is at the same time environmentally ef- fective, economically efficient and equitable. To fight increasing inequality and improve the political acceptability of decarbonization, these distributive effects need to be addressed. Otherwise, a political backlash is likely to appear (Boyer *et al.* 2020). Of course, adverse distributional effects do not call for non-action since it would make everyone worse off. In this sense, the trade-off between environment and equity is absent. The question that arises concerns the design of environmental policies in order to minimize the inequality gap.

This study provides evidence of sizable costs caused by a road supply reduction in a city. Due to the non-linear impacts of car flow on pollution and congestion, policymakers should pay attention to the characteristics of the roads on which traffic is likely to be shifted: the initial level of traffic, the initial level of pollution, the composition of the population living nearby and the number of credible alternatives in place. In fact, even if car usage were to decrease in the short run, a road closure might still generate consequent costs in commuting time and air pollution if traffic is displaced to (more) congested roads. Conversely, the overall impacts on pollution and congestion can be mitigated if (i) traffic is displaced to less congested roads and (ii) a large enough fraction of commuters drop their car.

In the case of Paris, since traffic was displaced to more congested roads, I show significant costs in terms of pollution and time loss. Although the costs are spread in different areas of the city, low-income households are more impacted by higher exposure to air pollution. Indeed, almost 90% of the pollution cost is borne by residents living near the periphery of the city, who might not use private cars to commute but still pay the price of the policy. Also, it is worth noting that many of them live outside of the local jurisdiction responsible for this closure. This brings into question the political economy behind this type of policy. In fact, the Mayor of the city caters each policy to the needs of local constituents, feeding socio-economic and political sorting. On the one hand, she may be right if we consider that suburban commuters should not have crossed Paris in the first place, generating negative externalities in a city for which they do not pay local taxes. On the other hand, higher levels of decision-making might be tempted to sacrifice the city, as proven by then plan autoroutier de Pompidou: plan conceived in the mid-1960s with the aim of providing Paris with a fine network of freeways and "fluidified" roads inside the ring road in order to link Paris to its suburbs.[42]

[42] The primary interest of the plan was to link Paris to the suburbs by means of entirely roadway links, thus freeing the city from traffic congestion. Most of the planned infrastructures were finally abandoned following the 1973 oil crisis and the arrival of Valéry Giscard d'Estaing to the power. The only concrete achievement of this plan remains the Georges-Pompidou expressway, built on the banks of the Seine river in 1966.

Regarding the case of Paris, an eastern itinerary was removed for car commuters. The alternative in terms of public transportation is the train line linking the west and the east of the region (RER-A).[43] However, it is the most used urban train in Europe, which makes it extremely saturated during peak hours. Reducing a road lane of the same direction is therefore unlikely to provoke a shift of some commuters on public transportation. The alternative in terms of roads is restricted to local roads or the ring road. However, with an initial high number of cars on the ring road and low-income households living nearby, large consequences could not have been avoided in the absence of credible alternatives.

As such, one way of mitigating the costs of this policy would be to implement policies in favor of a mode switch along with the closure. In fact, I show that if 50% of inner city-commuters and 10% of suburban commuters had dropped their car, congestion and pollution would not have increased on substitute roads. For instance, why not implement the Grand Paris Express project before reducing the road supply in the city?[44] Of course, both projects have different time spans. The Grand Paris Express project takes almost a decade to be put in place while the closure of a road can be done in a day.

7. References

Adler M.W. and van Ommeren J.N. (2016), *Does Public Transit Reduce Car Travel Externalities? Quasi-Natural Experiments' Evidence From Transit Strikes*, «Journal of Urban Economics», 92, pp. 106-119

Akbar P. and Duranton G. (2017), *Measuring The Cost Of Congestion In Highly Congested City: Bogotá*, CAF Development Bank of Latin America Working Paper No. 04

Anderson M.L. (2020), *As The Wind Blows: The Effects of Long-Term Exposure to Air Pollution on Mortality*, «Journal of the European Economic Association», 184, pp. 1886-1927

Apur (2016), *The Parisian ring road at the centre of the metropolis*, Atelier Parisien d'Urbanisme

Ardekani S. and Herman R. (1987), *Urban Network-Wide Traffic Variables and Their Relations*, «Transportation Science», 21, 1, pp. 1-16

Batterman S.A., Zhang K. and Kononowech R. (2010), *Prediction and Analysis of Near-Road Concentrations Using a Reduced-Form Emission/Dispersion Model*, «Environmental Health», 9, 1, pp. 1-18

Bhalla K., Shotten M., Cohen A., Brauer M., Shahraz S., Burnett R., Leach-Kemon K., Freedman G. and Murray C.J. (2014), *Transport for Health: The Global Burden of Disease from Motorized Road Transport*, The World Bank

Bouleau M. (2013), *La circulation routière en Île-de-France en 2010*, IAU Île-de-France

[43] The RER-A is the main transport line in Paris' region that links the west and east of the city.

[44] Today, the metro and RER form a hub-and-spoke network with Paris at its center. The Grand Paris Express is meant to complete this system with the construction of four new metro lines around the capital (15, 16, 17 and 18) by 2028, serving the inner and outer suburbs. One of the direct benefits is the relief of some public transport lines that would otherwise be saturated.

Boyer P., Delemotte T., Gauthier G., Rollet V., Schmutz B. *et al.* (2020), *The Gilets Jaunes: Offline and Online*, Tech. rept., CEPR Discussion Papers

Chapelle G., Wasmer E., and Bono P.H. (2020), *An Urban Labor Market with Frictional Housing Markets: Theory and an Application to The Paris Urban Area*, Journal of Economic Geography, 21, 1, pp. 97-126

Chay K.Y., and Greenstone M. (2005), *Does Air Quality Matter? Evidence from the Housing Market*, «Journal of political Economy», 113, 2, pp. 376-424

Currie J. and Walker R. (2011), *Traffic Congestion and Infant Health: Evidence from E-Zpass*. «American Economic Journal: Applied Economics», 3, 1, pp. 65-90

Davis L.W. (2008), *The Effect of Driving Restrictions on Air Quality in Mexico City*, «Journal of Political Economy», 116, 1, pp. 38-81

de Grange L. and Troncoso R. (2011), *Impacts of Vehicle Restrictions on Urban Transport Flows: The Case of Santiago, Chile*, «Transport Policy», 18, 6, pp. 862-869

Downs A. (1962), *The Law Of Peak-Hour Expressway Congestion*, «Traffic Quarterly», 16, 3

Duranton G. and Turner M.A. (2011), *The Fundamental Law Of Road Congestion: Evidence From Us Cities*, «American Economic Review», 101, 6, pp. 2616-2652

European Environmental Agency, EEA (2020), *Transport: Increasing Oil Consumption and Greenhouse Gas Emissions Hamper EU Progress Towards Environment and Climate Objectives*, European Environmental Agency

Gallego F., Montero J.-P. and Salas C. (2013), *The Effect of Transport Policies on Car Use: Evidence From Latin American Cities*, «Journal of Public Economics», 107, pp. 47-62

Geroliminis N. and Daganzo C.F. (2008), *Existence of Urban-Scale Macroscopic Fundamental Diagrams: Some Experimental Findings*, «Transportation Research Part B: Methodological», 42, 9, pp. 759-770

Gibson M. and Carnovale M. (2015), T*he Effects of Road Pricing on Driver Behavior and Air Pollution*, «Journal of Urban Economics», 89, pp. 62-73

Gonzalez-Navarro M. and Turner M.A. (2018), *Subways and Urban Growth: Evidence from Earth*, «Journal of Urban Economics», 108, pp. 85-106

Gu Y., Jiang C., Zhang J. and Zou B. (2021), *Subways and Road Congestion*, «American Economic Journal: Applied Economics», 13, 2, pp. 83-115

Hall F.L. (1996), *Traffic Stream Characteristics. Traffic Flow Theory*, US Federal Highway Administration, 36.

Haywood L., Koning M. and Prud'homme R. (2018), *The Economic Cost of Subway Conges-Tion: Estimates from Paris*, «Economics of Transportation», 14, pp. 1-8

Immers L.H. and Logghe S. (2002), *Traffic Flow Theory*, Faculty of Engineering, Department of Civil Engineering, Section Traffic and Infrastructure, Kasteelpark Arenberg, 40, 21

Kang C.D. and Cervero R. (2009), *From Elevated Freeway to Urban Greenway: Land Value Impacts of the Cgc Project in Seoul, Korea*, «Urban Studies», 46, 13, pp. 2771-2794

Kean A.J., Harley R.A. and Kendall G.R. (2003), *Effects of Vehicle Speed and Engine Load on Motor Vehicle Emissions*, «Environmental science & technology», 37, 17, pp. 3739-3746

Kornhauser A. and Fehlig M. (2003), *Marketable Permits for Peak Hour Congestion in New Jersey's Route 1 Corridor*, in *TRB 2003 Annual Meeting* (03-3465)

Liu L.N. and McDonald J.F. (1999), *Economic efficiency of second-best congestion pricing schemes in urban highway systems*, «Transportation Research Part B: Methodological», 33, 3, pp. 157-188

Lorente A., Boersma K.F., Eskes H.J., Veefkind J.P., Van Geffen J.H.G.M., de Zeeuw M.B., van der Gon H.A.C.D., Beirle S. and Krol M.C. (2019), *Quantification of Nitrogen Oxides Emissions From Build-Up of Pollution over Paris With TROPOMI*, «Scientific reports», 9, 1, pp. 1-10

Lozhkina O.V. and Lozhkin V.N. (2016), *Estimation of Nitrogen Oxides Emissions from Petrol and Diesel Passenger Cars by Means of On-Board Monitoring: Effect of Vehicle Speed, Vehicle Tech-Nology, Engine Type on Emission Rates*, «Transportation Research Part D: Transport and Environment», 47, pp. 251-264

Mink J. (2022), *Putting a Price Tag on Air Pollution: The Social Healthcare Costs of Air Pollution in France*, Paris, Sciences Po

On the Health Effects of Traffic-Related Air Pollution. Health Effects Institute, Panel 2010, Traffic Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects, Boston, Health Effects Institute, Special Report 17

Pandian S., Gokhale S. and Ghoshal A.K. (2009), *Evaluating Effects of Traffic and Vehicle Characteristics on Vehicular Emissions Near Traffic Intersections*, «Transportation Research Part D: Transport and Environment», 14, 3, pp. 180-196

Poole Jr R.W. and Orski C.K. (2000), *Hot Lanes: A Better Way to Attack Urban Highway Congestion*, «Regulation», 23, 15

Prud'homme R., Koning M. and Kopp P. (2011), *Substituting a Tramway to a Bus Line in Paris: Costs and Benefits*, «Transport Policy», 18, 4, pp. 563-572

Santos G., Button K. and Noll R.G. (2008), *London Congestion Charging*, Brookings-Wharton Papers on Urban Affairs, pp. 177-234

Small K.A. and Verhoef E.T. (2007), *The Economics Of Urban Transportation*, London-New York, Routledge

Sullivan D.M. (2016), *The True Cost of Air Pollution: Evidence from House Prices and Migration*, Discussion Paper 69, Cambridge (MA), Harvard University

Tirachini A. and Hensher D.A. (2012), *Multimodal Transport Pricing: First Best, Second Best and Extensions to Non-Motorized Transport*, «Transport Reviews», 32, 2, pp. 181-202

WHO (2005), *Health Effects of Transport-Related Air Pollution*, WHO Regional Office Europe

– (2017), *Preventing Noncommunicable Diseases (Ncds) by Reducing Environmental Risk Factors*, Tech. rept. World Health Organization.

Winston C. and Langer A. (2006), *The Effect of Government Highway Spending on Road Users' Congestion Costs*, «Journal of Urban Economics», 60, 3, pp. 463-483

Appendix

A Chronology of the Georges Pompidou riverbank closure decision

In December 2015, the Paris Council shared the thoughts of a plan concerning the pedestrianization of some riverbanks. The shutdown of 3.3 kilometers of the Georges Pompidou riverbank from the Tuileries to the Henry IV tunnel was first declared the 26th of September 2016 through deliberation. The October 18th, 2016 decree formalized the creation of a pedestrian area; however, it was contested due to the displacement of pollution and noise generated by this decision. On February 21st 2018, the administrative tribunal of Paris canceled the Paris Council's September 26, 2016 deliberation, and the town hall's 18th of October 2016 decree creating a public walk on the location of this riverbank. However, on the 6th of March 2018, a decree was created forbidding vehicle circulation on a segment of the riverbank for reasons related to site protection and enhancement for touristic and aesthetic pur- poses. Many associations and individuals asked for the annulment of this decree at the administrative tribunal of Paris. Their voices were heard and on October 22nd, 2018 the annulment was confirmed due to doubts concerning the environmental consequences of this project. Lastly, on June 21st 2019, the Paris Council confirmed the 6th of March 2018 decree while rejecting all the related annulment appeals.

B Public transportation

This section explores whether some people have shifted onto public transportation and, more precisely, on the line A of the rail network that cuts across the Paris region from the west to the east with several stations in the suburbs and Paris.[45]

Population Census. Intuitively, individuals commuting by car from the west to the east and vice versa are the people potentially impacted by the GP closure. If the GP closure increased the commuting cost such that the cost of using public transportation becomes lower, one might expect a modal shift away from car-based transportation. Since the line A of the rail network cuts across the Paris region the same way the GP riverbank does (west-east), it would be the most credible alternative. Hence, we should expect an increase in its use after September 1st, 2016.

Since the riverbank itinerary was an eastward road used to cross Paris, I focus on commuters that can substitute their GP car travel itinerary with public transportation. As mentioned above, the A- line crosses the region the same way the GP did. Hence, it can be considered as a car-substitute for individuals impacted by the policy. Conversely, the B-line of the network would be only indirectly impacted by the GP shutdown since individuals who were commuting by car through the GP itinerary are unlikely to have shifted to a train linking the north and south of the region.

[45] The RER is the suburban train network in the Paris region. The RER-A (or A-line) links the west and the east of the region, while the RER-B (or B-line) links the north and the south. Figure G.13 represents these two lines in the Paris region.

First, using the population census of 2015 and 2017 I compute the share of people commuting by public transportation for each dyad composed of the home place and work place. Figure G.12 shows that the share of people commuting with public transportation from west to east or east to west is high, whether individuals live near a station of RER-A or not. Nonetheless, individuals who commute from west to east or vice versa and who live in a municipality through which the line A passes tend to use slightly more public transportation.[46] Conversely, the remaining dyads[47] have a low share of public transportation usage, regardless of the presence of a train station of RER-A in the home municipality. We can note in each case that the difference between the share of public transport commuters in 2015 and 2017 is negligible, if not zero. These results suggest that (i) the individuals potentially touched by the GP closure were already using intensely the public transport system, and (ii) at first sight, there is no suggestive evidence that the riverbank shutdown provoked an increase in the use of public transportation.

I evaluate the causal effect of the GP closure on the share of public transportation commuters in a difference-in-difference design. I use the dyads in which the home municipality hosts an A-line station as the treatment group and the dyads in which the home municipality hosts a B-line station as the control group. The result of this difference-in-difference estimation is represented in column (1) of Table F.6. To go further, I restrict the treated group to the east-west and west-east travels and the control group to the north-south and south-north travels.[48] This allows me to capture the effect on commuters crossing Paris in the same direction as the ones who were commuting through the GP riverbank itinerary prior to 2016. The result is shown in column (2). The dynamic impacts are shown in graph G.14.

Tap Validations. One might argue that the share of people commuting by public transport in the years before and after the riverbank shutdown are not comparable since Paris has been subject to many urban alterations the past decade as mentioned in the introduction. To address this issue, I last turn to an alternative dataset on the number of pass validations of the A-line and B-line at the daily level. This would allow me to compare the number of pass validations on both train lines right around the cutoff (see Figure G.15), where both train lines should be comparable.

I therefore estimate another version of equation (5) using the data from March 2016 to end of January 2017, where Yit now represents the number of weekly entries of station i at time t. The graphical results are shown in Figure G.16 and suggest again the absence of significant change in the use of the A-line right after the GP closure.

All of the above suggest that, at least in the short run, the policy did not trigger a mode shift.

[46] However, the difference is not statistically significant.

[47] All travels excluding West-East and East-West.

[48] I consider all the municipalities of the following departments as West: 92, 78, 95 and the municipalities of the following departments as East: 93, 94, 77, 93. As for the North municipalities, I select the ones in the departments 93, 95 and the municipalities of the South are the ones of the department 91. Note, that I do not include the municipalities of Paris in the home place (to avoid having people who commute inside Paris), but I do include them in the workplace since many jobs can be located inside the city.

C Housing prices

Results so far suggest that the GP closure increased traffic and nitrogen dioxide emissions on substitute roads. This section explores whether, on top of experiencing an increase in congestion and nitrogen dioxide emissions, substitute roads also encountered other negative externalities. Chay and Greenstone (2005) show that the elasticity of housing prices to pollution ranges between -0.20 and -0.35. Hence, in the worst case, prices would have decreased by 1.96% near the ring road. I evaluate the impact on the housing prices near the ring road and assess whether the magnitude is larger than the one expected from a single increase in nitrogen dioxide.

Empirical Strategy. I make use of housing transactions data to evaluate the impact on transacted prices of apartments close to the south part of the ring road. As mentioned, the ring roads delimit the city of Paris. The *Boulevard des Maréchaux* (Boulevards of the Marshals) are a collection of thoroughfares that encircle the city of Paris just inside its city limits. The ring road and the *Boulevard des Maréchaux* are 350 to 400-meters apart.[49] This provides a setup where the air near the *Boulevard des Maréchaux* is less likely to be contaminated with the increase of pollution on the ring roads. I use this separation to compare houses close to similar amenities (close to the limits of the city, close to a major road) with one particular difference: the ring road experienced an increase in traffic and pollution while the other road is left untouched. Therefore, I compare before and after the policy, transacted prices of houses outside of Paris near the south ring road with transacted prices of houses inside Paris near The Boulevards of the Marshals (see Figure G.18). I vary the bandwidth selected bearing in mind that houses closer to the ring roads should be more impacted than houses further away. I estimate the following hedonic regression:

$$ln(HV_{it}) = \beta ln(BA_i) + \theta Rooms_i + \sum_{k=-2,k\neq-1}^{+2} \gamma_k Treated_i * Year_{k(t)} + \delta_{m(t)} + \delta_{n(i)} + \epsilon_{it} \tag{13}$$

where HV_{it} is the price of transaction i at date t. BA_i is the built sare which represents the surface in squared meters of transaction i, Roomsi represents the number of rooms that apartment i possesses. $Treated_i$ is a dummy variable that takes the value 1 if transaction i is located outside the limits of the city and 0 otherwise. $Year_{k(t)}$ is the year relative to the GP shutdown of date t and $\delta_{m(t)}$ and $\delta_{n(i)}$ are respectively month of the sample and neighborhood fixed effects.

Results Figure G.19 represents the plots of the leads-and-lags regression of equation (13). The impact is negative and statistically significant in 2017. The magnitude of the impact is higher the smaller the bandwidth. However, the impact of 2018 reached 0 and becomes non-statistically significant. This is explained by the announcement made in February 2018 regarding the implementation of new metro lines in the south of Paris.[50]

[49] In between, I find almost no housing transactions since it is occupied by public social housings.

[50] https://www.societedugrandparis.fr/gpe/actualite/la-nouvelle-feuille-de-route-du-grand-paris-express-1683.

D Calculating the 2016 GP closure costs in Euro value

The 2016 GP closure displaced congestion and pollution to other substitute roads. However, since the impacts on traffic and pollution are non-linear the overall impact might change. To measure the costs of this policy, I quantify the impacts of an increase in pollutant emissions and an increase in travel time among the treated population.

D.1 Pollution Cost

To measure the change in pollution, the ideal data set would have all types of pollution (local particles, global pollution, noise pollution etc.), at the road level at a granular time window. In reality, pollution data is much more limited. Instead, I can look at the source of nitrogen dioxide emissions NO_2 at an hourly level near the east of the ring road and the upper banks. Provided that the relationship between average speed on the road and NO_2 emissions is well estimated, I find a causal impact on NO_2 emissions of +5.8% on the south ring road and +1.5% on the upper banks. This represents an increase of roughly 1 $\mu g/m^3$ near local roads and an increase of 3.8 $\mu g/m^3$ near the ring roads compared to the levels of 2015 (cf. Table F.5). I can do some back-of-the-envelope calculations to estimate the magnitude of this change in emissions. Mink (2022) finds that an increase in 1$\mu g/m^3$ of NO_2 emissions is associated with 15.08 e per day per postcode for big cities in France.[51] I use the estimates from Mink (2022) to quantify the cost of 1μg/m3 health cost expenditure in France. However, these estimates are estimated using a sample the size of 1/97 of the total French population with 6,048 postcodes.[52] Hence, the total cost per postcode per day must be multiplied by 97 in order to have a sense of the true impact. The increase in pollution on local roads affect 5 municipalities. However not all residents of these 5 municipalities are impacted. The increase in pollution near the ring roads affect 10 municipalities. To this matter, I consider that only half of these residents suffer from the increase of pollution on these local roads. The healthcare costs associated with the increase of pollution for the 260 working days of the year near the upperbanks correspond to $15.08 \times 97 \times 5/2 \times 260 \times 1 = 950, 794$, and near the ring roads of $15.08 \times 97 \times 10/2 \times 260 \times 3.75 = 7, 226, 034$.

D.2 Time Loss

In order to compute the time loss for commuters due to the decrease in the average speed, I first predict what would have been the average speed on each road in the treated roads had the policy not taken place (cf. Table F.8). Two categories of commuters are suffering from an increase in travel time. First, direct losers are diverted commuters. The difference in travel time consists of the difference between the travel time using the GP expressway and the travel time using the diverted itinerary. Second, indirect losers are commuters initially on substitute roads. Adding additional users on the road decreases the average speed on that road and hence increases their

[51] In Mink (2022), healthcare costs caused by exposure to moderate levels of air pollution in France are quantified using an instrumental variable approach where wind speed is an instrument for air pollution.

[52] The study is conducted on a representative sample of the administrative data on healthcare reimbursements from French National System of Health Data.

travel time. The difference in travel time consists of the difference between the travel time on the treated road had the policy not taken place and the actual travel time during the post-shutdown period. Ex-riverbank users would use the entire expressway for a travel time of 24.4 minutes. If they substitute the expressway with the south outer ring road, they lose 4 minutes. If they circumvent the closed section with local roads they lose 13 minutes. Commuters initially on the local roads suffer from an increase of 2.6 minutes in their commuting time. Commuters initially on the ring road experience an increase of 4 minutes on the 10.4-kilometer ring road. In order to quantify in Euro Value the costs of time losses, I use the value of time proposed by the French governement and used for cost/benefit analysis.[53] An hour in the Île-de-France region is valued at 13.4. A minute costs 0.22. To this matter, I compute the daily cost of an increase in the travel journey for each category of commuter. Numbers are shown in Table F.9.

D.3 Maximum distance closed that keeps suburban commuters on local roads

I can compute the maximum length that would keep suburban commuters on local roads. In order to do so, I equalize the average travel time when suburban commuters stay on local roads to the average travel time when suburban commuters shift on the ring road. If all commuters shift on local roads, the extra car density becomes 47, which accounts for 62% of the pre-shutdown density. Using the congestion elasticity of local roads, I find that speed decreases by 54%, which brings it back to an average speed of 6.4km/h. This gives:

$$
\begin{aligned}
(1-x)S_e + xS_a &\leq S_f \\
x(S_e - S_a) &\geq S_f - S_e \\
x(6.4 - 30) &\geq 25 - 30 \\
x &\leq 0.2
\end{aligned}
$$

The maximum fraction of road that can be pedestrianized without provoking the shift of suburban commuters on the ring road is 0.2. This represents 2.6-kilometers of the GP riverbank.

E Calculating the Costs of Counterfactual Situations in Euro Value

E.1 Car-ban in the center of Paris

In order to compute the costs of counterfactual situations, I first need to predict what would have been the traffic and pollution situation in each hypothetical situation. Regarding the traffic situation, I use the elasticity of congestion estimated and the predicted number of commuters who shifts on each substitute road to compute the predicted average speed. Regarding the pollution situation, I use the elasticity of NO_2 emissions with respect to the average speed and the impact on speed predicted from the model to predict the change in NO_2 emissions. The counterfactual situation where the center of Paris is closed to car circulation removed the upperbank from the choice set of substitute roads. Therefore, all inner-city commuters refer on the boulevard saint germain.

[53] https://www.ecologie.gouv.fr/sites/default/files/V.3.pdf.

The 6,500 suburban commuters are untouched by the policy since they switch to the south ring road, loosing 4 minutes. Similarly, the 60,790 individuals initially on the south ring road are not differently impacted, with a time loss of 4 minutes as well. However, inner-city commuters are impacted. Density of cars increases by 34% on the boulevard saint germain, decreasing speed by 33.7% on that road. This leads to a time loss of 28.5 minutes for diverted commuters and 10.3 minutes for commuters initially on the boulevard. The time cost in this is is the following:

$$260 \times 0.22(6,500 \times 4 + 60,790 \times 4 + 20,700 \times 28.5 + 19,400 \times 10.3) = 60.5M$$

As for the pollution cost, residents living near the south ring road suffer from the same pollution cost since the traffic situation on that road remains unchanged. On the contrary, a smaller fraction of people are now impacted by an increase of pollution in the center since the number of roads impacted by a decrease in the average speed decreased. However, the magnitude of the impact on the average speed (and therefore on pollution) is higher. In this case, only 2 municipalities are impacted by a deterioration in air quality. The pollution cost is:

$$15.08 \times 97 \times 2/2 \times 260 \times 0.09 \times 63 \times 34\% = 733,176$$

E.2 Changing the length of the road closure

There are four different stages. The first one is when the length of the closed segment is between 0 and 2.6-kilometers. Below 2.6-kilometers, suburban commuters shift on local roads. However, in that case, the upperbank is the only substitute road available. The second stage corresponds to a length of 2.6 to 3.3-kilometers of road closure. In that case, suburban commuters shift to the ring road and inner-city commuters stay on the upperbanks. The third stage corresponds to the actual situation of a 3.3-kilometer closure. Here, the boulevard saint germain becomes a local substitute road. Inner-city commuters shift on both local roads and suburban commuters divert to the ring road. Last, above 3.3-kilometers, the upperbanks stay a local substitute road on the whole length since it is reachable anywhere from the GP. However, since the boulevard saint germain only has one entrance and exit, it can only serve as a substitute for 3.5-kilometers. After that, all inner-city commuters shift back on the upper banks.

E.3 Minimum mode switch needed for zero net pollution costs

If we take the scenario where all commuters shift on local roads to avoid displacing externalities to the periphery, one can compute the average speed needed so that suburban commuters choose local roads instead of the ring road. In that case, commuting time using the ring road should be higher than travel time using expressway and local roads. The minimal average speed needed woulf be:

$$\frac{D_{e,non-closed}}{S_{e,non-closed}} + \frac{D_{local}}{S_{local}} < \frac{D_{ringroad}}{S_{ringroad}}$$

$$\frac{9.7}{30} + \frac{3.3}{S^*} < \frac{10.4}{25}$$

$$S^* > 35.4$$

F Appendix tables

TABLE F.1 • TRAFFIC BY ROAD

Table E.1: Traffic by road

	Pre-shutdown			Post-shutdown		
	Density	Speed	Flow	Density	Speed	Flow
Panel A: Non-pedestrianized stretch of the riverbank						
Morning	55	30.5	2,300	44.4	25	1,677
Evening	70	26.3	2,369	47.7	23.7	1,875
Dayweek & Daytime	54.5	30	2,239	42.8	25.1	1,741
Panel B: Pedestrianized stretch of the riverbank						
Morning	40.3	44.5	2,068	-	-	-
Evening	60	42.3	2,307	-	-	-
Dayweek & Daytime	46.3	44.6	2,083	-	-	-
Panel C: South outer Ring Road						
Morning	62.4	28.6	4,807	66.6	26	4,563
Evening	84.6	20	4,347	91	16.8	3,994
Dayweek & Daytime	71	25	4,676	75.5	22	4,366
Panel D: Upper Banks						
Morning	63.4	15.07	1,533	80.5	12.7	1,565
Evening	76.7	15.3	1,770	103	12.1	1,787
Dayweek & Daytime	69.3	14.8	1,584	90.4	12.1	1,611
Panel E: Bd Saint Germain						
Morning	85.5	8.9	1,311	120	8.4	1,545
Evening	121.5	9.6	1,816	167	7.9	1,901
Dayweek & Daytime	103	8.7	1,487	142	7.8	1,634
Panel F: Bd Saint Germain & Upper Banks						
Morning	67.3	13.9	1,491	89.1	11.7	1,560
Evening	84.4	14.3	1,779	116	11.1	1,816
Dayweek & Daytime	75.2	13.7	1,566	101	11.2	1,616

Notes: The speed is expressed in km/h. All speeds are computed for daytime during weekdays. The average speed on each road is computed using the weighted average of speeds on each arc of road. The flow represents the average number of cars on each arc of road in an hour. the occupancy rate is in percentage, and represents the percentage of the road that is occupied by cars in an hour.

TABLE F.2 • AVERAGE TRAVEL TIME IN THE PRE-SHUTDOWN PERIOD

Itinerary	Time	Travel Time
Expressway	Morning	24 minutes
Expressway	Evening	27 minutes
Expressway + local roads	Morning	33 minutes
Expressway + local roads	Evening	36 minutes
South outer ring road	Morning	22 minutes
South outer ring road	Evening	31 minutes

Notes: The travel time of each itinerary is computed using the data of the pre-shutdown period summarized in Table F.1 by computing $TravelTime = \frac{Length}{Speed}$. The first itinerary is the expressway where the non-pedestrianized stretch accounts for 9.7km and the pedestrianized for 3.3km. The second itinerary is the expressway of the non-pedestrianized stretch and the local roads (Bd Saint Germain or upper banks) instead of the pedestrianized stretch. The last itinerary is the south outer ring road that is of 10.4 km.

TABLE F.3 • ROBUSTNESS CHECKS: OCCUPANCY RATE

	(1)	(2)	(3)	(4)	(5)
			Occupancy rate (in log)		
			Ring Roads		
Treatment	0.112***	0.117***	0.112***	0.112***	0.112***
	(0.018)	(0.018)	(0.018)	(0.024)	(0.018)
Constant	3.146***	3.071***	3.158***	3.146***	3.146***
	(0.005)	(0.068)	(0.006)	(0.006)	(0.005)
Observations	765,044	765,044	765,047	765,044	765,044
R^2	0.569	0.297	0.372	0.569	0.569
			Local Roads		
Treatment	0.339***	0.357***	0.339***	0.339***	0.339***
	(0.080)	(0.084)	(0.079)	(0.089)	(0.080)
Constant	2.233***	2.142***	2.247***	2.233***	2.233***
	(0.024)	(0.091)	(0.015)	(0.027)	(0.024)
Observations	1729726	1729726	1729733	1729726	1729726
R^2	0.579	0.250	0.482	0.579	0.579
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Clustering	Arc	Arc	Arc	Between Entries	Arc
Trimmed data	No	No	No	No	Yes

* p<.10, ** p<.05, *** p<.01

Notes: The outcome is the log of occupancy rate. Column (1) represents the main estimation during daytime. Columns (2) to (5) represent the different robustness checks performed to validate the results. In column (2), I include the dummy variable Treated instead of arc fixed effects. In column (3), the fixed effects are decomposed into year, month of the year, day of the week and hour of the day referred to as *additive time FE*. In column (4) clusters are composed of arcs between two entries. Column (5) adds up a restriction to the data: the data are winsorized at the 1% level.

TABLE F.4 • ROBUSTNESS CHECKS: FLOW

	Ring Road		Upper Banks	
Year	Mean	Sd. Dev.	Mean	Sd. Dev.
2013	75.6	47	66.7	31.7
2014	74.7	36.5	62.08	30.5
2015	67	34.8	60.4	30.6
2016	66.2	34.8	59,3	28.7
2017	64.8	34.3	58.6	30.05
2018	67.4	33	59	29.8

Notes: This table represents the average and standard deviation of NO_2 emissions two sensors: the one located on the upper banks and the one on the east of the ring road. NO_2 emissions are measure in $\mu g/m^3$.

TABLE F.6 • IMPACT ON THE SHARE OF PEOPLE COMMUTING BY PUBLIC TRANSPORTATION

	(1)	(2)
	Share of public transportation commuters	
Treatment	0.002	-0.001
	(0.002)	(0.006)
Constant	0.405***	0.709***
	(0.000)	(0.001)
Observations	38,921	3,362
R^2	0.980	0.959
Dyad FE	Yes	Yes
Year FE	Yes	Yes
Travels	All	West-Est + North-South

* p<.10, ** p<.05, *** p<.01

Notes: Standard errors are in parentheses and clustered at the dyad level. The equation estimated is the following: $Y_{it} = \lambda_t + \psi_i + \gamma \mathbb{1}\text{treated}_i = 1 \mathbb{1}\text{post=1} + \epsilon_{it}$ where i represents the dyad, t the year and Y_{it} the share of public transportation of dyad i at date t. The dummy variable treated equals to 1 if the line A passes through the home municipality of the dyad and 0 if the line B passes through the home municipality. The dummy variable *post* takes the value 1 the GP riverbank is closed on year t (year>2015) and 0 otherwise. The first column represents the estimate when all travels are included. The second column restricts the sample to west-east (and east-west) and north-south (and south-north) travels.

TABLE F.7 • COUNTERFACTUAL - SPEED IMPACT PREDICTED BY THE MODEL

Distance closed	Inner-city	Suburbans	Impact on local roads	Impact on ring road
From 0 to 2.6km	On upperbanks	On upperbanks	-57%	-
From 2.6 to 3.3	On upperbanks	On ring road	-45%	-17%
3.3km	On upperbanks & bd St germain	On ring road	-18&	-17&
>3.3km	On upperbanks & bd St germain(for 3.3km)	On ring road	-18&	-17&

Notes: For each length window presented in column 1, I display which road inner-city commuters divert on in column (2), which road suburban commuters divert on in column (3) and their corresponding speed impacts in the remaining two columns.

TABLE F.8 • SPEED PREDICTIONS

Road	Speed Pre-shutdown	Speed Post-shutdown (predicted)	Actual Speed post-shutdown
South Outer Ring Road	25	25.6	22
Local Roads	13.9	13.16	11.2

Notes: For each treated road, the average speed in the pre-shutdown period is taken from the data. The average predicted speed post-shutdown is the speed predicted in the post-shutdown period had the policy not taken place. The actual speed postshutdown is the average speed observed on each road after the policy implementation. The speed is expressed in km/h. All speeds are computed for daytime during weekdays. The average speed on each road is computed using the weighted average of speeds on each arc of road.

TABLE F.9 • TIME LOSS IN EURO VALUE

Commuters	Time lost	Daily Cost in €	Yearly Cost in €
Ex-riverbank diverted to the ring road	4	0.88	228.8
Ex-riverbank diverted to local roads	13	2.86	743.6
Commuters on ring road	4	0.88	228.8
Commuters on local roads	2.6	0.57	148.72

Notes: I consider that commuters experience an increase in travel time only during weekdays. I multiply the daily cost by 260 days to obtain the yearly cost. Since the expressway is a unique flow direction road, only one way of the commuting trip is impacted. The westward trip of each commuter remains unchanged with no additional cost associated.

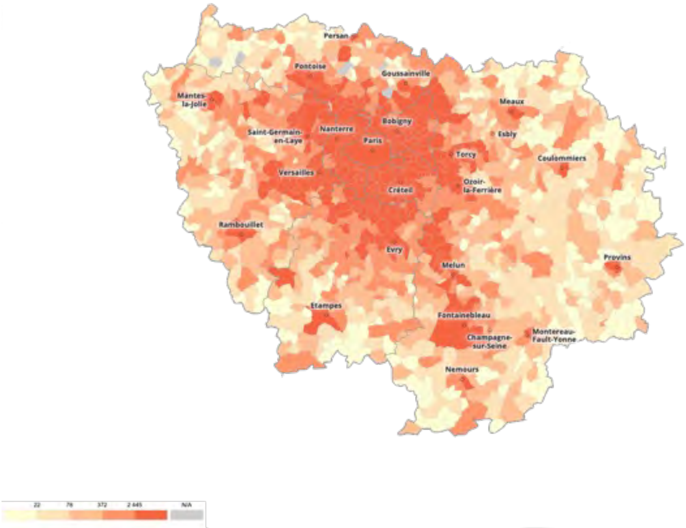
TABLE F.10 • SPEED - COUNTERFACTUALS SITUATIONS

Distance closed	Inner-city	Suburbans	Speed Before	Speed After
0 to 2.6	upper banks	upperbanks	14.8	6.4
2.6 to 3.3	upperbanks	ring road	14.8	8.5
3.3	upper banks and st germain	ring road	13.7	11.3
Above 3.3	upper banks and st germain	ring road	13.7	11.3 on 3.5km 8.5 on the remaining length

Notes: The first column indicates the length (in kilometers) of the closed segment of the GP expressway. The second column indicates on which road inner-city commuters divert to. The third column indicates where do suburban commuters shift on. The fourth column indicates the average speed (in km/h) on the diverted road before the GP closure. The last column indicates the predicted speed (in km/h) on the diverted road if commuters shift on it.

G Appendix Figures

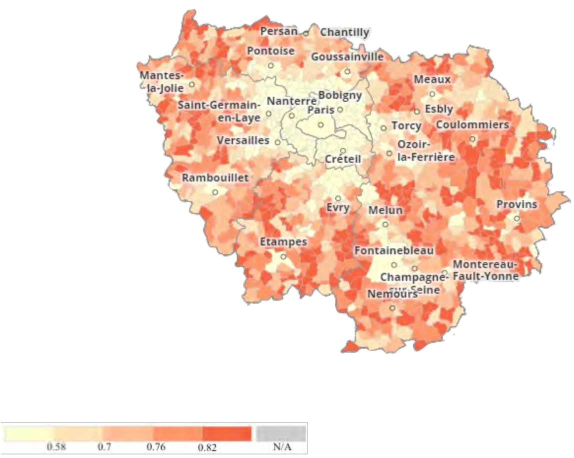
FIGURE G.1 • JOB CONCENTRATION IN 2015



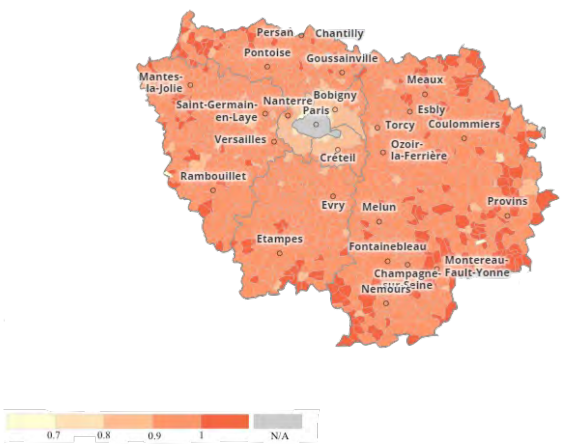
Notes: The job concentration is represented on this graph which is the absolute value of the number of jobs taken from the DADS (Déclaration Annuelle de Données Sociales). The brighter the color, the fewer the number of jobs in the region.

FIGURE G.2 • FRACTION OF PEOPLE COMMUTING BY CAR IN ÎLE-DE-FRANCE (2015)

(a) All journey



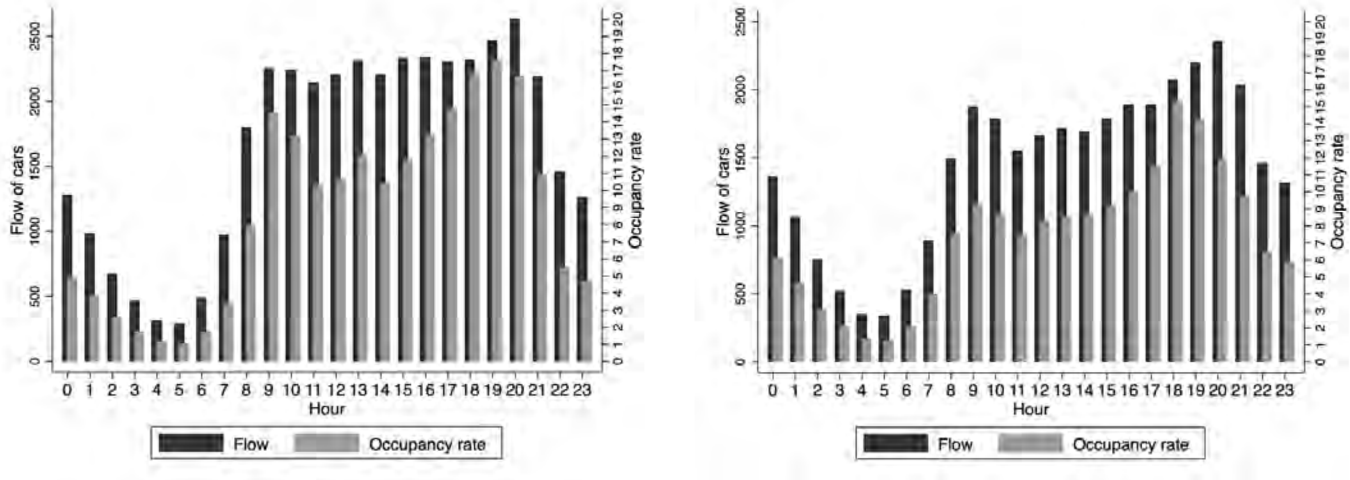
(b) Suburb-to-suburb journeys



Notes: These graphs represent the fraction of individuals commuting by car in Île-de-France. The data is taken from INSEE - "Recensement 2015". A low fraction of car commuters is represented by a brighter color.

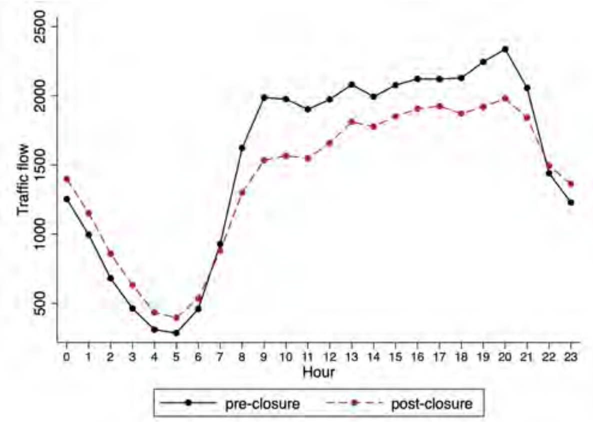
FIGURE G.3 • DESCRIPTIVE STATISTICS OF THE RIVERBANK - 2015

(a) 13 km riverbank (b) 3.3 km closed in 2016



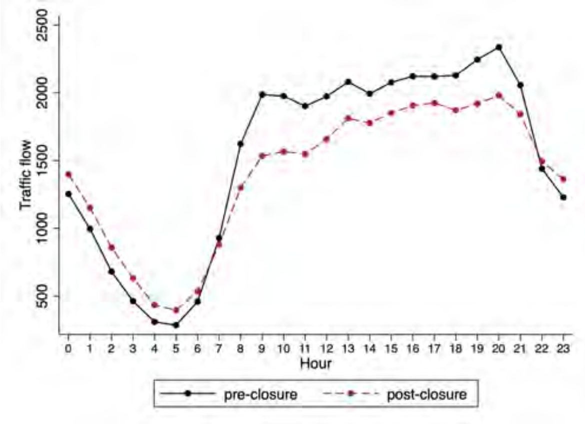
Notes: Data come from the open data source of the city hall. The sample in Figure G.3 (a) is composed of the 33 road sections that compose the GP riverbank inside the city. The sample in Figure G.3 (b) is composed of 7 road sections that represent the part of the GP riverbank to be pedestrianized.

FIGURE G.4 • FLOW ON THE PEDESTRIANIZED STRETCH



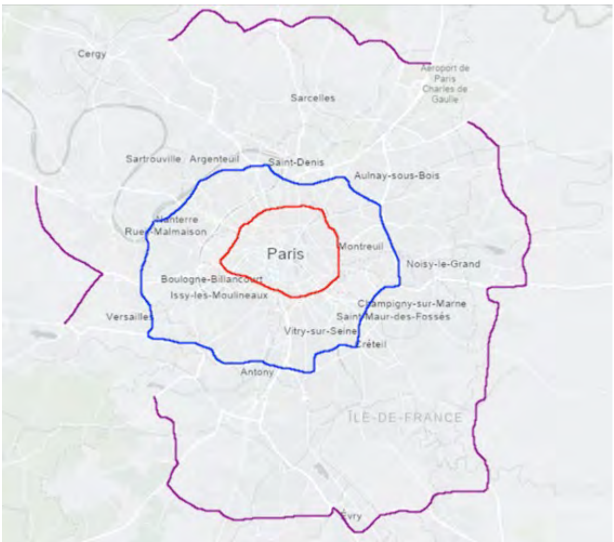
Notes: The sample is restricted to the 7 road sections that are pedestrianized as of 2016. The outcome is the flow of cars averaged on the pre-shutdown and post-shutdown period.

FIGURE G.5 • FLOW DIFFERENCE OF THE NON-PEDESTRIANIZED STRETCH, BEFORE AND AFTER THE 2016 SHUTDOWN



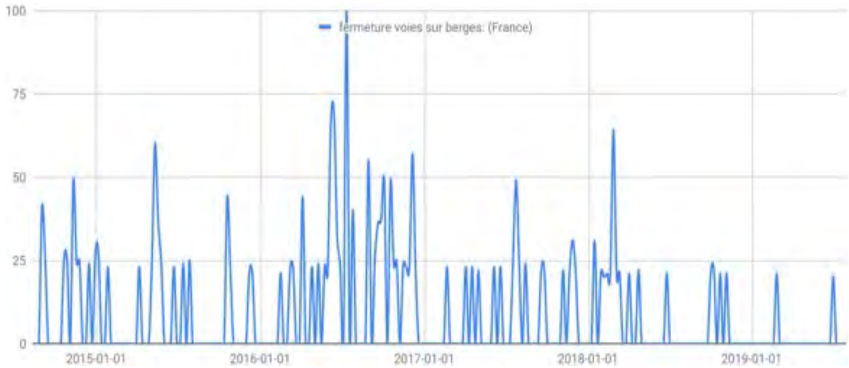
Notes: The sample excludes the 7 road sections that are pedestrianized as of 2016. The outcome is the flow of cars averaged in the pre-shutdown and post-shutdown period.

FIGURE G.6 • THE THREE BYPASSES ENCIRCLING PARIS



Notes: The red bypass represents the ring roads called *Boulevard Périphérique*. The second bypass (blue) is the A86 highway. The third and incomplete one (purple) represents the *Francilienne*.

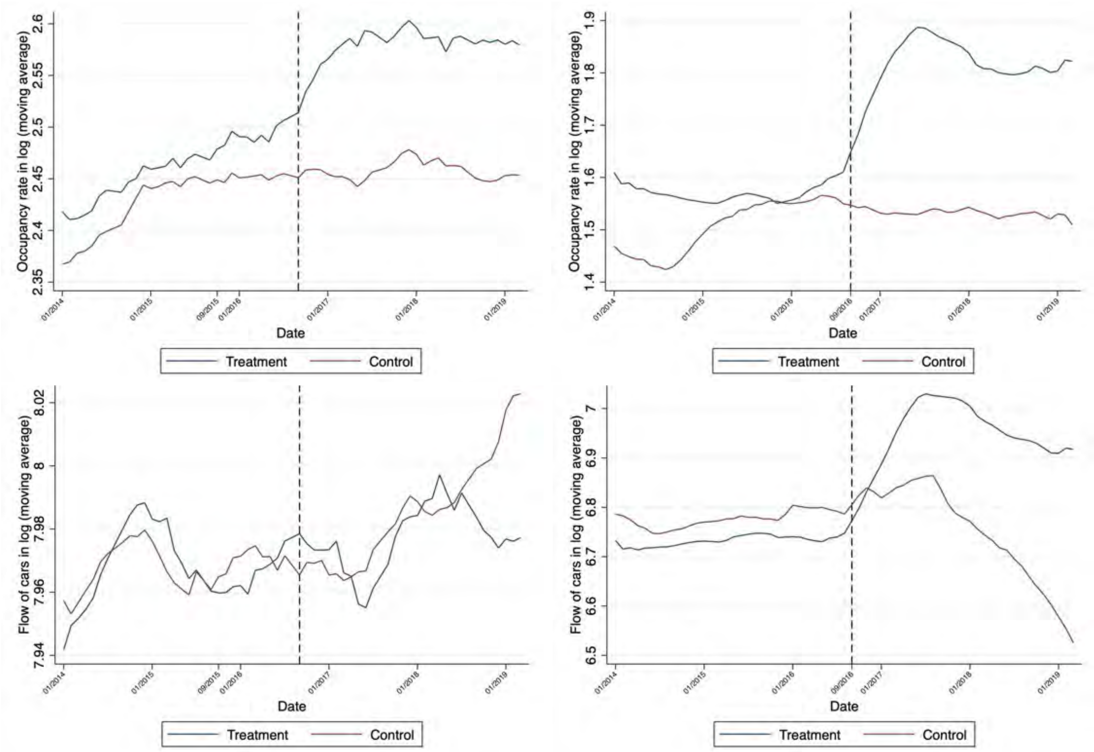
FIGURE G.7 • GOOGLE TREND



Notes: This graph represents the *Google trend* of the number of times that people in France googled "Fermeture des voies sur berges", which literally means "Riverbanks closure".

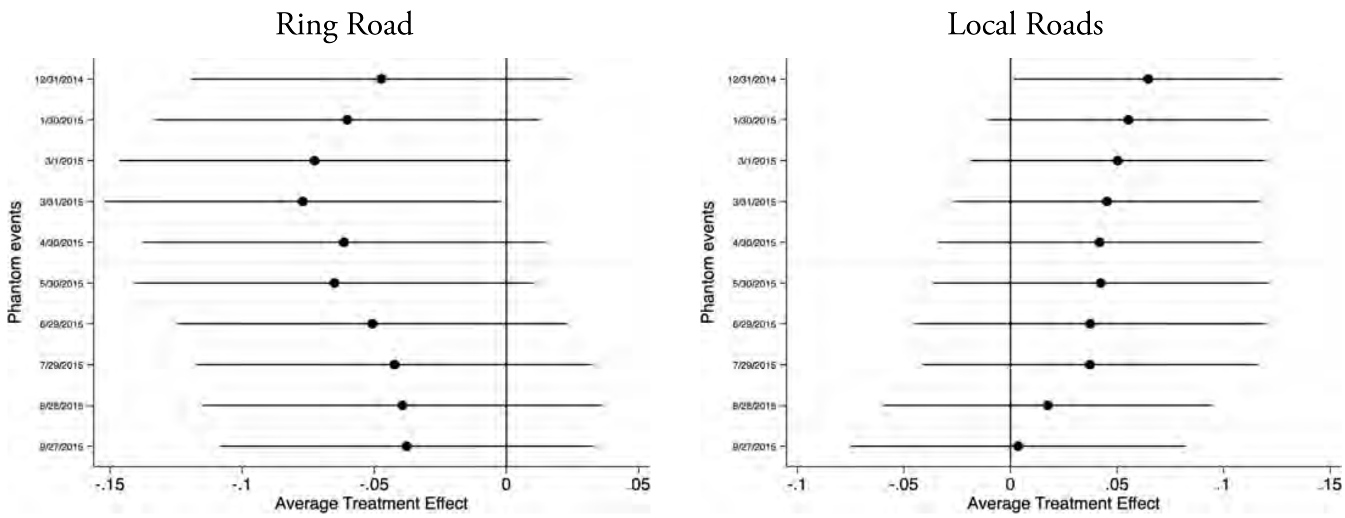
FIGURE G.8 • COMMON TRENDS

Ring Road | Local Roads



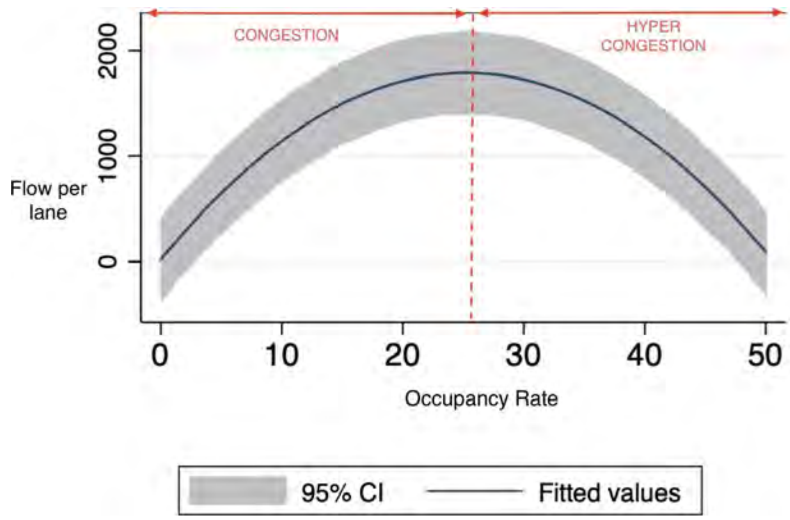
Notes: Theses graphs represent the common trend assumptions of the difference-in-difference research design. The first row is the common trends on the occupancy rate. The second row is the common trends on the flow of cars. The average occupancy rate is calculated with a moving average of a window of (11 1 0): the window includes the current month as well as the previous 11 months in order to smooth the noise over the year.

FIGURE G.9 • PLACEBO TESTS



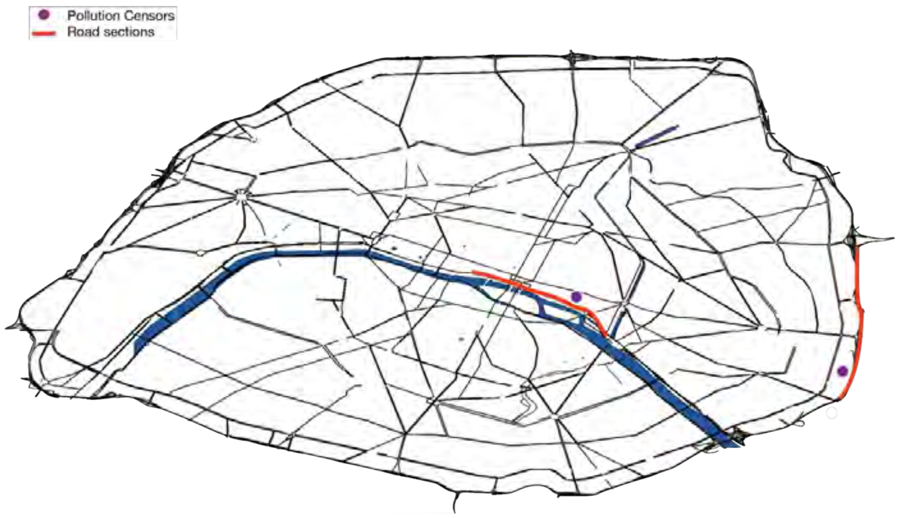
Notes: I use data from January 1, 2013 to September 1, 2016. Starting from January 1, 2015 I create every 30 days a phantom event and run regression (4) during the day and for weekdays with the average speed as the outcome variable. These graphs plot the estimates and 95% confidence intervals of this regression.

FIGURE G.10 • FUNDAMENTAL DIAGRAM



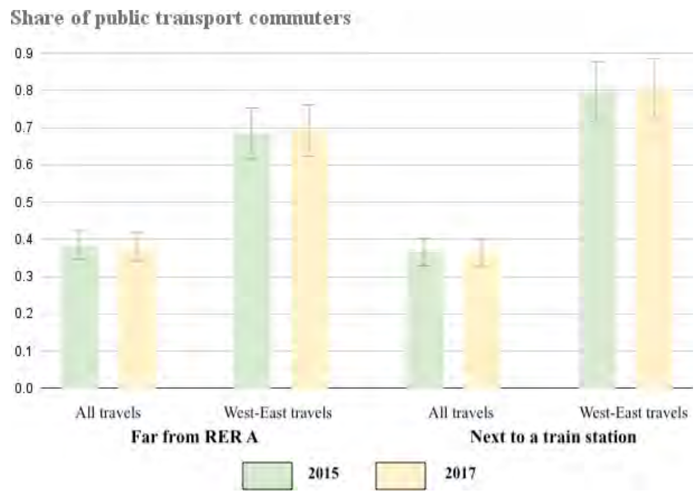
Notes: I estimate the concave relationship between Flow per lane and occupancy rate of one arc of road. The ascendant part of the graph is what we define as the *congested* part, while the descendant part is the *hyper-congested* one.

FIGURE G.11 • POLLUTION MONITORS AND ROAD SECTIONS SELECTED



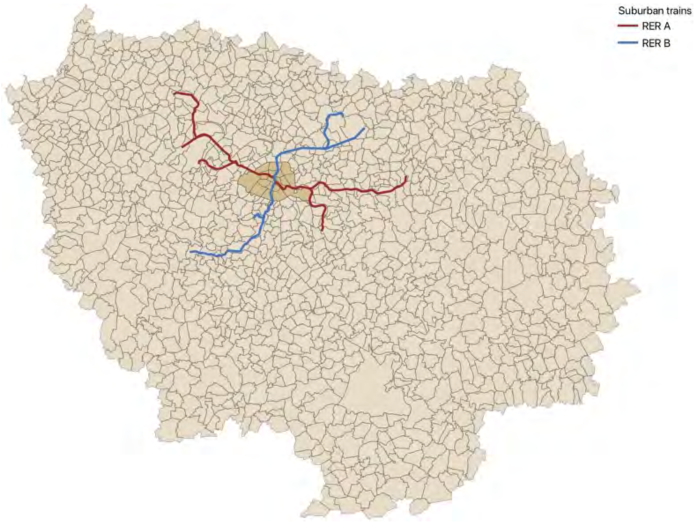
Notes: This map represents the two monitors I use for my analysis. One is located in the center near the upper east and one on the east of the ring road. The line in red represents the arcs of road selected near each monitor.

FIGURE G.12 • SHARE OF PUBLIC TRANSPORT COMMUTERS IN 2015 AND 2017



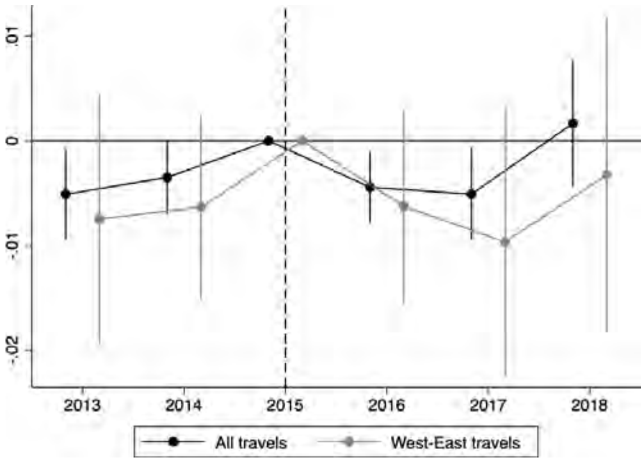
Notes: This chart compares the share of people commuting in public transportation in 2015 and 2017. The outcome is the mean of the share of public transportation usage in the dyads considered. The first part of the chart considers the dyads whose home municipalities do not have a station of the RER-A: "Far from RER-A". The last part of the chart considers the dyads whose home municipalities have a station of the RER-A: "Next to a train station". For each part, I distinguish between the west-east travels and all travels excluding the west-east ones.

FIGURE G.13 • PUBLIC TRANSPORTATION - RER-A AND RER-B



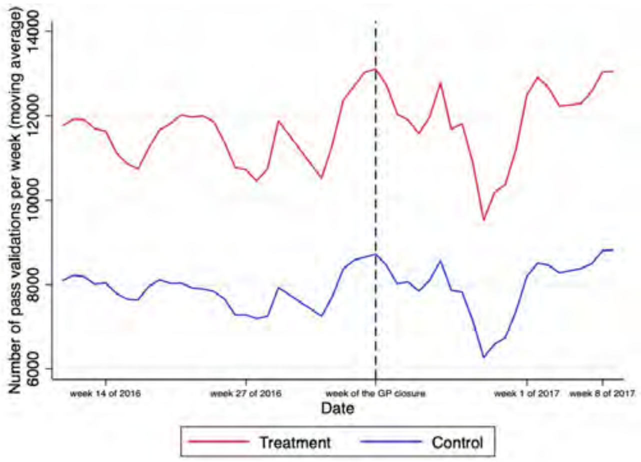
Notes: This figure represents the two train lines used in the analysis. The A-line is represented by the red line. The B-line by the blue line.

FIGURE G.14 • SHARE OF PUBLIC TRANSPORTATION



Notes: This graph represents the estimates of equation:
$Y_{it} = \lambda_t + \psi_i + \sum_{k=2013}^{2018} \beta_t 1_{treated_i=1} 1_{t=k} + \epsilon_{it}$ where i represents the dyad, *k* the year and Y_{it} the share of public transportation of dyad *i* at date *t*. The dummy variable treated equals to 1 if the line A passes through the home municipality of the dyad and 0 if the line B passes through the home municipality. 2015 is the reference year and all the impacts are normalized to 2015. The black line represents the estimates when all travels are included. The gray line represents the estimates when the sample is restricted to west-east (and east-west) and north-south (and south-north) travels.

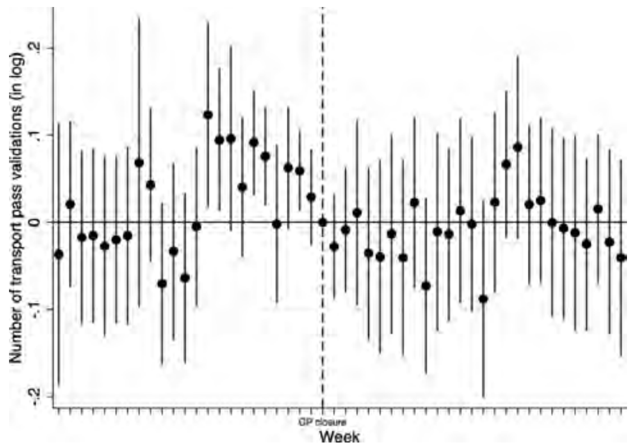
FIGURE G.15 • WEEKLY NUMBER OF VALIDATIONS - RER-A AND RER-B



Notes: I plot the moving average of the number of weekly validations between March 1, 2016 and February 2, 2017, excluding the days between July 23, 2016 and August 21, 2016 as the RER-A was going through renovation works. The moving average is computed with a window of (0 1 3), which includes the current week and the three next weeks. The vertical dashed black line represents week 35 of 2016, the before the riverbank shutdown.

I therefore estimate another version of equation (5) using the data from March 2016 to end of January 2017, where Y_{it} now represents the number of weekly entries of station *i* at time *t*. The graphical results are shown in figure G.16 and suggest again the absence of significant change in the use of the A-line right after the GP closure.

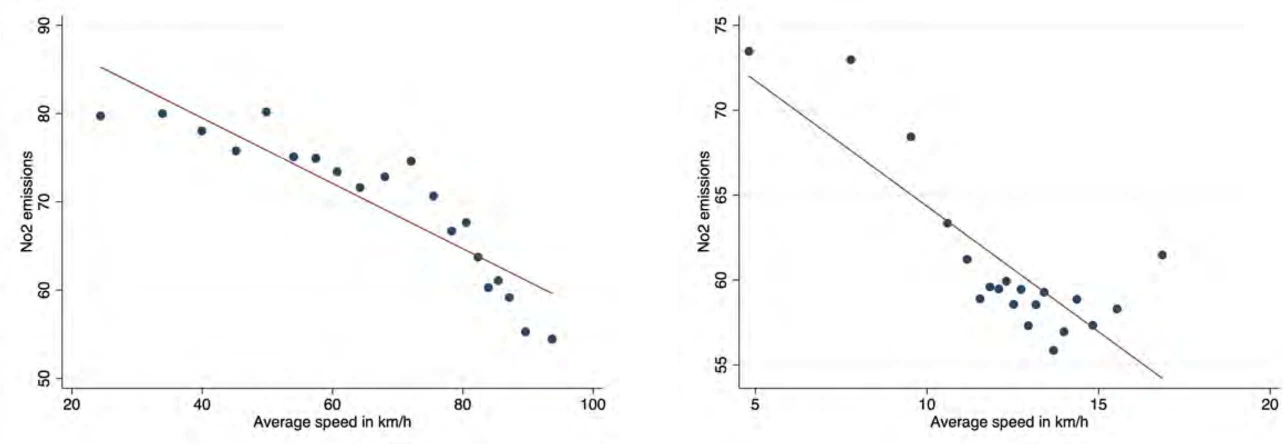
FIGURE G.16 • IMPACT ON THE RER-A



Notes: In this graph, I plot the estimates of equation (5). λ_t and ψ_i are year and station fixed effects, respectively. The indicator variable $1_{\text{post=1}}$ equals 1 if the reform has been adopted (after September 1, 2016) and 0 otherwise. The dummy $1_{\text{treated}_i=1}$ takes the value 1 if station i is on RER-A and 0 if it is on RER-B. The sample includes the weeks between March 1, 2016 and February 2, 2017, excluding the days between July 23, 2016 and August 21, 2016 as the RER-A was going through renovation works. The vertical dashed black line represents week 35 of 2016, the before the riverbank shutdown.

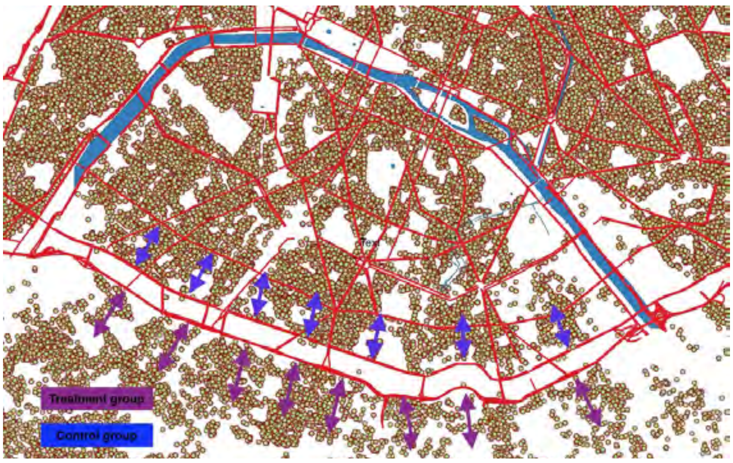
FIGURE G.17 • LINK BETWEEN NO_2 EMISSIONS AND AVERAGE SPEED

Ring Road | Upper Banks



Notes: These graphs plot the relationship between average speed on the road near the pollution censor and NO_2 emissions.

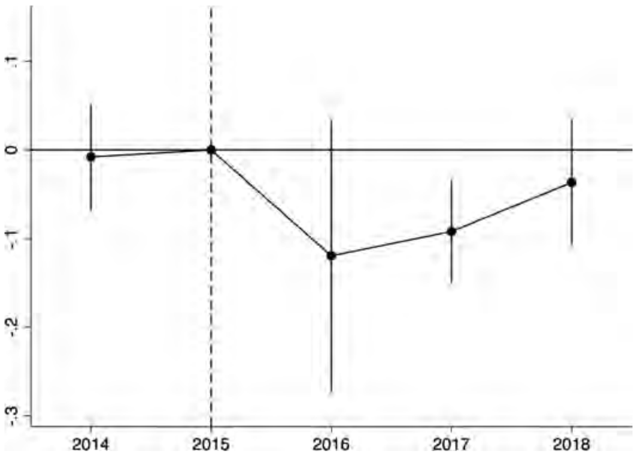
FIGURE G.18 • TREATMENT AND CONTROL GROUPS FOR HOUSING PRICES



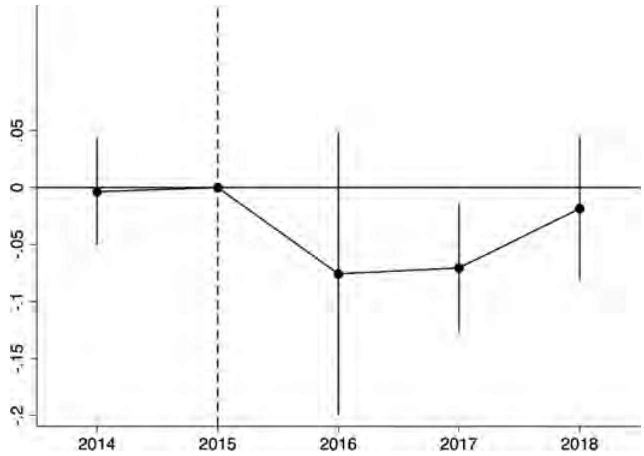
Notes: This graph represents all housing transactions from 2014 to 2018. There are two roads encircling the city. The first one is the "Boulevard des maréchaux" which is a boulevard inside the limits of the city. The second road is the ring road, which delimits the city of Paris. Transactions outside the limits of the city and close enough to the ring roads are impacted by the increase of negative externalities on the ring road and are considered as treated. Transactions near the "boulevard des maréchaux" are located at a distance of 350 to 400-meters from the ring roads and are therefore less likely to be impacted by the increase in negative externalities on the ring road. They are consist of the control group.

FIGURE G.19 • IMPACT ON HOUSING PRICES

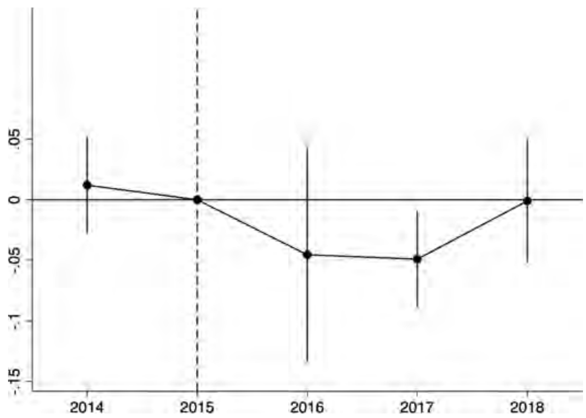
300-meters



500-meters

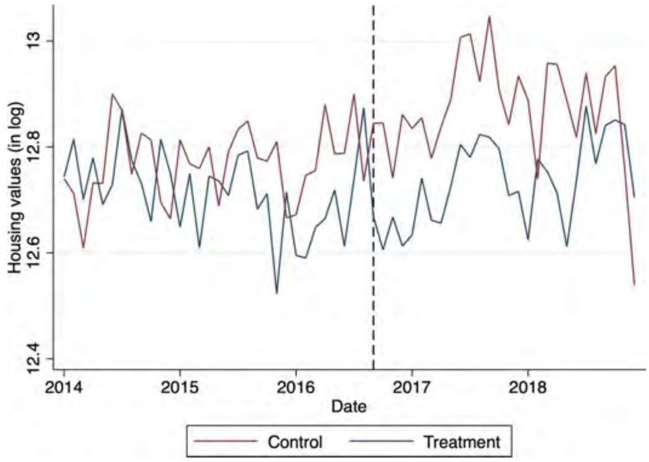


700-meters



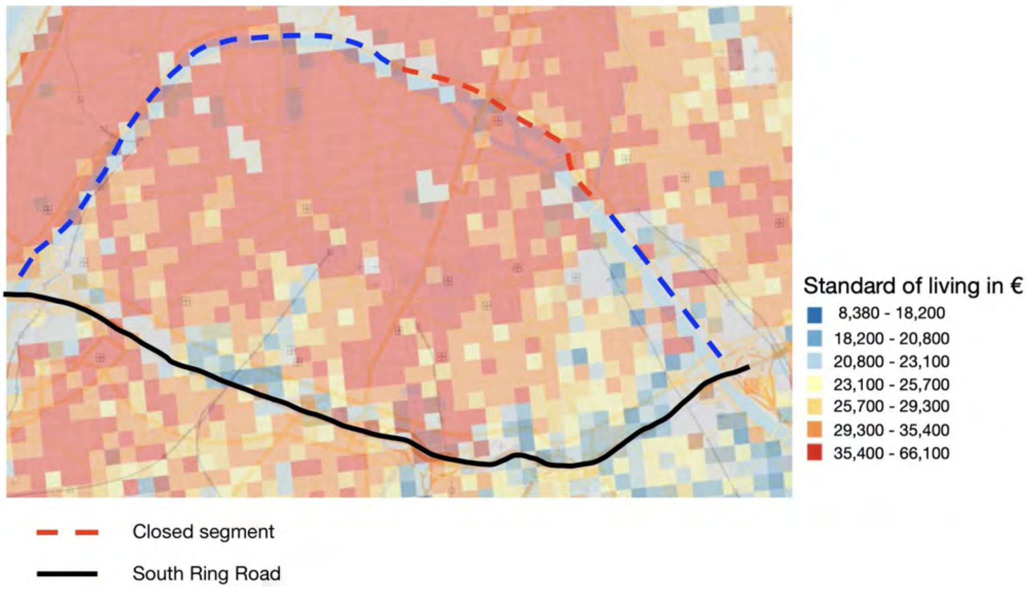
Notes: The outcome is the log of the transacted price. The reference year is 2015, a year before the GP shutdown. The regression is run on apartments only. Townhouses are removed from the sample. The sample consisting of transactions within 300-meters of the major road is composed of 5,769 observations. The sample consisting of transactions within 500-meters of the major road is composed of 11,119 observations and within 700-meters of 11,950 observations.

FIGURE G.20 • COMMON TREND ASSUMPTION - HOUSING TRANSACTIONS



Notes: This graph plots the common trend of the transacted price in log for treatment and control groups within 700-meters of the main road. The treated group is composed of the transactions within 700-meters of the south outer ring road. The control group is composed of transaction within 700-meters of the *Boulevard des maréchaux*. Both groups are represented in figure G.18.

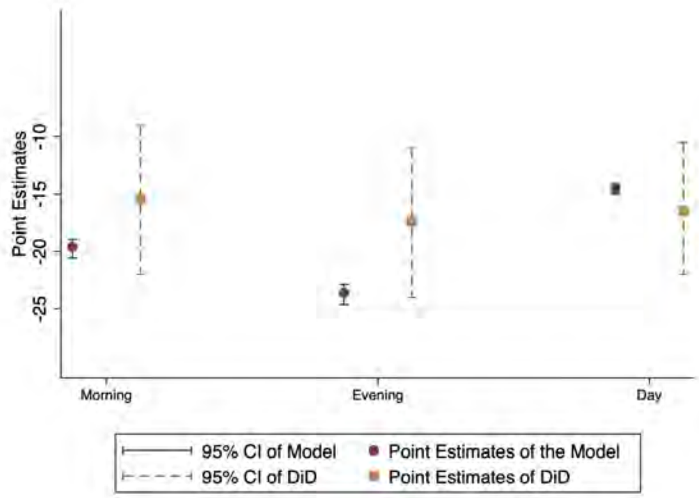
FIGURE G.21 • STANDARD OF LIVING ACROSS THE PARIS REGION



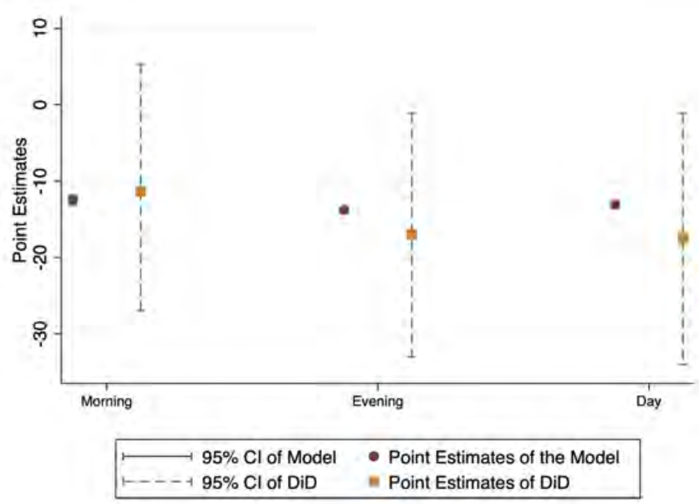
Notes: This map represents the spatial distribution of income near the treated roads. Red squares represent richer areas while blue squares represent poorer areas.

FIGURE G.22 • MODEL ESTIMATES VERSUS DID ESTIMATES

(a) Ring Road



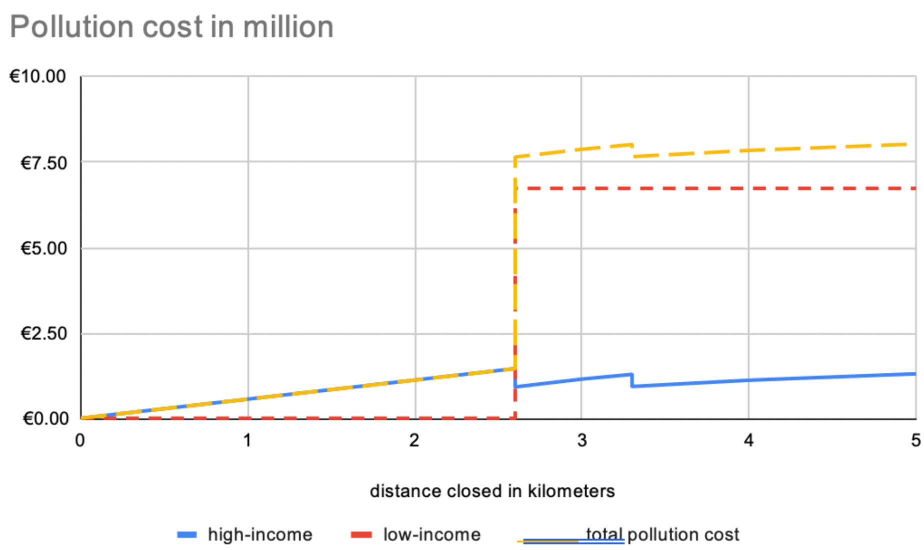
(b) Local Road



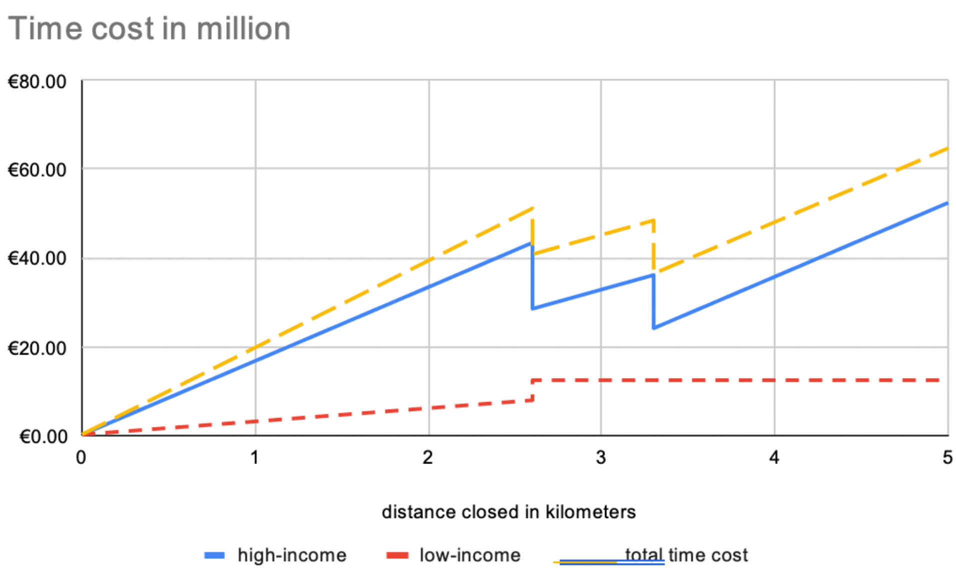
Notes: These graphs show the difference in point estimates between the impact of the GP closure on the average speed computed using the model, and the one computed using the difference-in-difference strategy. The model estimates are computed using the congestion elasticity σ of each time period.

FIGURE G.23 • COSTS IN COUNTERFACTUAL SITUATIONS

(a) Time Cost



(b) Pollution Cost



Notes: These graphs represent the costs of the policy with respect to the distance of the GP closed. Computations are described in Appendix E. All costs are computed using the speed impacts from the model's predictions.

Urban Economies as Complex Systems *è il titolo dell'undicesima edizione del Premio Giorgio Rota, i cui vincitori – Luca Favero, Ilaria Malisan, Giacomo Rosso e Léa Bou Sleiman – sono stati premiati in occasione della XI Giorgio Rota Conference il 30 maggio 2023 al Campus Luigi Einaudi. Il volume che raccoglie i saggi vincitori è introdotto da Francesca Silvia Rota dell'Università di Torino IRCrES CNR.*

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Urban Economies as Complex Systems *is the title of the eleventh edition of the Giorgio Rota Prize, whose winners – Luca Favero, Ilaria Malisan, Giacomo Rosso and Léa Bou Sleiman – were awarded at the XI Giorgio Rota Conference on 30 May 2023 at the Luigi Einaudi Campus. The volume collecting the winning essays is introduced by Francesca Silvia Rota of the University of Turin and IRCrES CNR.*

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