

## Category Real Estate

### **Title: Externalities, compensations and demographics**

**Supervisor: Nicolas Duran** ([n.duran@maastrichtuniversity.nl](mailto:n.duran@maastrichtuniversity.nl))

**Short text:** Negative externalities from economic activity affect millions of individuals around the world, with households residing close to where these activities take place being disproportionately affected. As a consequence, people move away from the externality source, which drives housing prices down and encourages lower income households to move in instead. While granting compensations for these externalities can, in theory, have a mitigating effect, little is known about both, the migrating patterns that negative externalities kindle, and how compensations for those mediate these trends.

With data from earthquakes induced by gas extraction and compensations granted by the gas extracting firm in the north of the Netherlands, this thesis will analyze the immigration patterns in terms of origin and income observed in the region during the period in which earthquakes were prevalent. Moreover, the analysis will pay special attention to how compensations that began to be granted at large to homeowners in the area in 2012 affected these trends.

#### **Data Sources:**

Earthquakes data from KNMI  
Compensations data from NAM  
Neighborhood data from CBS

#### **Requirements:**

Strong analytical and programming skills, preferably in R.

#### **References:**

Bakkensen, L. A., & Ma, L. (2020). Sorting over flood risk and implications for policy reform. *Journal of Environmental Economics and Management*

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### **Title: Solar panel adoption and housing prices**

**Supervisor: Nicolas Duran** ([n.duran@maastrichtuniversity.nl](mailto:n.duran@maastrichtuniversity.nl))

**Short text:** As climate change looms as an existential threat, the decision to adopt renewable energy sources at the household level is fundamental going forward. However, there are only a few estimates of the capitalization of solar panels into housing prices, which constitutes a major drive in the decision. In general, the literature has struggled in disentangling the adoption of solar panels with other characteristics of the house or neighborhood that could correlate with the decision to adopt them. This thesis will look at the capitalization of installing solar panels on housing prices in the north of the Netherlands using a compensating mechanism over earthquakes as exogenous variation for the adoption decision.

Induced earthquakes from gas extraction have been a feature of the north of the Netherlands for decades. The firm that extracts the gas in the region has, for the most part, denied that damages appearing on houses in the area were a consequence of these earthquakes. This has made residents very skeptic of the firm and the Dutch Government (the gas exploitation is a joint venture between privates and the Government). Due to a strong earthquake impacting the region in 2012, the firm had to forcefully began granting compensations to homeowners claiming for damages to their houses or for the drop in its value. A good share of these compensations, aimed at restoring the firm's image, included the installation of solar panels on the house's roof. The thesis will look at the effect of this solar panels on the price of houses sold after having the panel installed due to the compensating mechanism.

#### **Data Sources:**

Earthquakes data from KNMI

Compensations data from NAM  
Neighborhood data from CBS

**Requirements:**

Strong analytical and programming skills, preferably in R.

**References:**

Dastrup, S. R., Zivin, J. G., Costa, D. L., & Kahn, M. E. (2012). Understanding the Solar Home price premium: Electricity generation and "Green" social status. *European Economic Review*

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**Title: Towards an Automated Valuation Model (AVM) for the Dutch Residential Market**

**Supervisors:** Nils Kok (n.kok@maastrichtuniversity.nl); Piet Eichholtz

(p.eichholtz@maastrichtuniversity.nl); Alexander Carlo

(a.carlo@maastrichtuniversity.nl); Stefan Flagner (s.flagner@maastrichtuniversity.nl)

**Short text:** The notion of automated (predictive) valuation has taken a firm hold in the US residential real estate market. From Zillow to Opendoor, the market for automatically generated values, rather than manual assessments of value, allows for faster underwriting and better risk management. But of course, much depends on the quality of data, the extent of contextual data inputs, and the quality of the machine learning model. This thesis topic is for MSc students that have strong statistical skills and familiarity with predictive modeling algorithms (e.g. XGBoost). Some knowledge on GIS applications is useful.

**Data Sources:**

- NVM data
- CBS data

**References** and background reading:

Kok et al. (2017). Big data in real estate? From manual appraisal to automated valuation.

**Requirements:**

Understanding of machine-learning based predictive models.

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**Title: Sustainability and the Cost of Commercial Mortgage Debt**

**Supervisors:** Nils Kok (n.kok@maastrichtuniversity.nl); Piet Eichholtz

(p.eichholtz@maastrichtuniversity.nl); Alexander Carlo

(a.carlo@maastrichtuniversity.nl); Stefan Flagner (s.flagner@maastrichtuniversity.nl)

**Short text:** There is abundant and convincing evidence that sustainable buildings perform well on a range of economic indicators, like value, rent level, occupancy rate, and risk. Recently, some research has also been performed that investigates the cost of capital to finance these buildings: see below for some references. However, this research is far less abundant, and there is lots of unexplored territory on this issue.

The central idea of this thesis proposal is to investigate this in a better way, using two datasets for the United States commercial real estate market: the RCA commercial real estate lending database to get information about loan pricing and default, and the LEED database to get information about the environmental performance of the buildings that serve as collateral to the mortgage loans. Empirically, the trick is to link these datasets, and to estimate a potential sustainability discount in the loan rates, as well as effects on subsequent loan default. Since the data is already at hand, this is a low-risk thesis. On the other hand, the empirical analysis requires excellent statistical skills.

**Data Sources:**

- RCA
- USGBC

**References** and background reading:

Green Buildings in Commercial-Mortgage Backed Securities, Xudong An and Gary Pivo, Real estate Economics, 2020.

Environmental Performance and the Cost of Capital: Evidence from Commercial Mortgages and REIT Bonds, P. Eichholtz, N. Kok, R. Holtermans and E. Yönder, Journal of Banking and Finance, 2019.

REIT Environmental Performance and the Cost of Equity, P. Barron, P. Eichholtz and E. Yönder, in The Routledge REITs Research Handbook 1st Edition, Ed. David Parker, 2018.

**Requirements:**

Statistical proficiency, using R or Stata.

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**Title: Explaining International Home Ownership**

**Supervisors:** Nils Kok (n.kok@maastrichtuniversity.nl); Piet Eichholtz

(p.eichholtz@maastrichtuniversity.nl); Alexander Carlo

(a.carlo@maastrichtuniversity.nl); Stefan Flagner (s.flagner@maastrichtuniversity.nl)

**Short text:** The housing market is the world's largest asset market, and private home ownership differs strongly across countries. That that has not received much attention in the academic literature, and it is not clear at all what causes these differences. The literature on home ownership focuses mostly on explaining home ownership differences within countries across households. The general conclusion is that rich households are likely to own their home, while poor households are more likely to rent. On the country level, we do not see this at all: Switzerland and Germany, both rich, have low home ownership, while Greece and Morocco, not so rich, both have very high home ownership. The purpose of this thesis/research project is to do an analysis on the country level, to try and explain this phenomenon.

Theoretically, the likely trade-off that people make when they decide to rent or own their own home is between the risk of renting (inflation risk) and the risk of owning (volatility of house prices). For this thesis, a student needs to look at house price risk for a large sample of countries, using existing data from the Bank for International Settlements, as well as inflation risk for these same countries, using data from the IMF or other sources. These can then be used as explanatory variables to explain home ownership. The main challenge in data collection is to get the home ownership data from national statistics bureaus, but these data are available, so this is mostly a matter of perseverance. Since changes in home ownership are very gradual, the thesis should go as far back in time as possible, probably to the 1970s.

**Data Sources:**

- BISS Data (Open Data)

**References** and background reading:

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**Requirements:**

Statistical proficiency, using R or Stata.

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**Title: Moving to Productivity II**

**Supervisors:** Nils Kok (n.kok@maastrichtuniversity.nl); Piet Eichholtz

(p.eichholtz@maastrichtuniversity.nl); Alexander Carlo

(a.carlo@maastrichtuniversity.nl); Stefan Flagner (s.flagner@maastrichtuniversity.nl)

**Short text:** Real estate sustainability has mostly been framed in terms of energy efficiency, but has other dimension as well, such as occupant health and productivity. Maastricht University works together with the city of Venlo in a number of studies concerning the relationship between indoor climate and worker productivity. The first of these is entitled "Moving to Productivity", which involved an extensive survey among office workers in Venlo before and after they moved from a conventional office building to a

building that was designed for an optimal indoor climate. All these four surveys took place before the Covid-19 crisis.

The idea for this thesis is to do a fifth survey that specifically compares the office work experience – using the data from the previous surveys – with the working-from-home experience. On top of that, we want to investigate sub-questions relating to the decision to come back to the office to work there (between June and September). The fifth survey will be based on the four previous ones, with some new questions added about the work environment as home. The survey infrastructure that we used before can be employed again for this study.

**Data Sources:**

- Gemeente Venlo

**References** and background reading:

Palacios et al. (2020). "Moving to productivity: The benefits of healthy buildings." PLOS One.

**Requirements:**

- Statistical proficiency, using R or Stata.
  - Speaking Dutch is very useful.
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**Title: Explaining Air Quality: A Global Study**

**Supervisors:** Nils Kok (n.kok@maastrichtuniversity.nl); Piet Eichholtz

(p.eichholtz@maastrichtuniversity.nl); Alexander Carlo

(a.carlo@maastrichtuniversity.nl); Stefan Flagner (s.flagner@maastrichtuniversity.nl)

**Short text:** Air quality has emerged as a hot topic (literally) not just in emerging economies like India and China, but also in developed nations such as the UK, the Netherlands, and the U.S. The air that we breath has implications for physical development and cognitive performance, and the body of evidence on this topic is increasing rapidly.

Most studies use satellite data to gain an understanding of local levels of air pollution, but such measures are not necessarily precise or accurate. Alternatively, most countries have local air quality measurement systems, but these are typically spread across large distances.

This thesis aims to use the data gathered by the network of installed sensors provided by PurpleAir, which has an "opt out" policy for each outdoor sensor that they sell to a customer (see the the PurpleAir website). With global data on air quality in hand, the question is what determines the cross-sectional variation in air quality, building a model that includes metrics such as local GDP, industry concentration, and urban development.

**Data Sources:**

- PurpleAir
- Local Census bureaus/agencies

**References** and background reading:

Air pollution lowers Chinese urbanites' expressed happiness on social media ([link](#))

Real estate valuation and cross-boundary air pollution externalities: evidence from Chinese cities ([link](#))

Self-protection investment exacerbates air pollution exposure inequality in urban China ([link](#))

**Requirements:**

Statistical proficiency, using R or Stata.

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**Title: Global investment performance in infrastructure****Supervisors: Nils Kok** (n.kok@maastrichtuniversity.nl); **Piet Eichholtz**(p.eichholtz@maastrichtuniversity.nl); **Alexander Carlo**(a.carlo@maastrichtuniversity.nl); **Stefan Flagner** (s.flagner@maastrichtuniversity.nl)

**Short text:** Pension funds and other institutional investors all over the world are increasingly investing in real assets, and infrastructure is one of the asset classes they look at. They mostly build up exposure to that asset class through unlisted vehicles, like private funds and funds-of-funds. However, there also is a growing group of listed infrastructure companies that provide an alternative, which may be cheaper and easier to access. Recently, these listed infra companies have bundled forces in an organization called GLIO, the Global Listed Infrastructure Organization. GLIO has also begun tracking the stock performance of these companies in an index. However, that index does not have a lot of history, so not much is known about the investment performance of these listed infrastructure companies in the medium to long term.

There are two theses to be written in this area:

Proposal 1. The purpose of the thesis is to study the performance of listed infrastructure companies over the longer term, for example the last 20 years, using the GLIO index as a basis, and creating an index that goes back further. Also, this thesis should look at the different type of infrastructure companies (energy, water, internet infra, roads, railroads and harbors, ...) and study performance differences. Data is from GLIO and FactSet.

Proposal 2. The purpose of the thesis is to look at the way pension funds invest in infrastructure: looking at investment approaches, costs, and realized performance. Maastricht University has access to the CEM global database of pension fund investment, which will be the basis of the empirical work. This thesis follow the recent work of Carlo et al. for real estate.

**References** and background reading:

Andonov, Eichholtz &amp; Kok (2015, Journal of Financial Markets)

Andonov, Eichholtz &amp; Kok (2013, Journal of Portfolio Management)

Carlo, Eichholtz &amp; Kok (2021, working paper)

Andonov, Kraussl &amp; Rauh (2018, SSRN working paper)

**Requirements:**

Statistical proficiency, using R or Stata.

**Title: Housing markets in the long run****Supervisor: Piet Eichholtz** ([p.eichholtz@maastrichtuniversity.nl](mailto:p.eichholtz@maastrichtuniversity.nl))

**Short text:** Housing has historically been a dominant component of overall private wealth, but its effects on economic decision-making and outcomes is not yet fully understood.

Specifically, there are three research questions that urgently need attention, and for which the data that is required to help get to an answer has become available. That implies there are three theses to be written about this.

Since Thomas Piketty wrote his famous "Capital in the 21<sup>st</sup> Century", the societal debate regarding wealth inequality has been gaining in intensity. Fears are that our societies are heading for a rigid divide between the haves and the have-nots. The recent COVID epidemic seems a case in point, with capital owners generally getting even more well-off than before the crisis, while non-capital owning workers have a hard time even just paying the rent. While Piketty and other researchers mention home ownership as a partial cause of the divide, they do not go into this very deeply. The purpose of the first thesis topic is to study how changes in house values over the very long run – in comparison to returns on other asset types – have contributed to wealth inequality. A group of researchers from

France, the Netherlands and the United Kingdom has collected archival data on housing and other portfolio assets for a large number of French citizens, and this dataset will form the basis of the thesis analysis. Small parts of the data still need to be digitalized by the thesis student: this mostly concerns the information that is needed to link different datasets.

**References:** Piketty, 2014., Piketty, Postel, Viney & Rosenthal, 2006. Piketty & Zucman, 2014.

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**Title: Housing markets in the long run**

**Supervisor: Piet Eichholtz** ([p.eichholtz@maastrichtuniversity.nl](mailto:p.eichholtz@maastrichtuniversity.nl))

**Short text:** Housing has historically been a dominant component of overall private wealth, but its effects on economic decision-making and outcomes is not yet fully understood. Specifically, there are three research questions that urgently need attention, and for which the data that is required to help get to an answer has become available. That implies there are three theses to be written about this.

Kahneman and Tversky have introduced the concept of loss aversion. Subsequent researchers have found that this – beside other aspects of behavioral economics – plays an important role in stock and option trading, as well as in housing markets. However, that research invariably looks at short-term historic data. The purpose of the second thesis topic is to look at loss aversion and the disposition effect in housing transaction in the very long run, based on a large set of data for Amsterdam. This is a rather ambitious topic. Looking evidence of loss aversion is not very difficult in itself, but the idea is to link different datasets, allowing for an analysis of issues that may affect loss aversion, like age, gender, capital losses or gains in other segments of the investment portfolio, economic experience, and the question whether house sellers bought or inherited the home. This topic requires quite a bit of analytical skill, but with the potential for a very high grade.

**References:** Eichholtz & Lindenthal, 2019. Kahneman & Tversky, 1974, 1979. Bokhari, Sheharyar, & Geltner. 2011. Crane & Hartzell. 2010. Genesove & Mayer. 2001.

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**Title: Housing markets in the long run**

**Supervisor: Piet Eichholtz** ([p.eichholtz@maastrichtuniversity.nl](mailto:p.eichholtz@maastrichtuniversity.nl))

**Short text:** Housing has historically been a dominant component of overall private wealth, but its effects on economic decision-making and outcomes is not yet fully understood. Specifically, there are three research questions that urgently need attention, and for which the data that is required to help get to an answer has become available. That implies there are three theses to be written about this.

Cities are at once static and dynamic. For example, in many European cities, the street grid established by the Romans can still be seen today. On the other hand, neighborhoods that were once thriving and prosperous can currently be poor, and vice versa. The purpose of the third thesis topic is to investigate the long-run persistence of location value in cities. Using data for Amsterdam, the analysis should look at the historic cross section of housing values, and its predictability for the current cross section. Would an investor be better off buying properties in high-value locations (which may reliably keep their value) or in low-value locations (which may increase in value)? The data for this thesis topic has already been collected.

**References:** Eichholtz, Geltner & Lindenthal, 2017. Eichholtz, Korevaar, Lindenthal, Tallec, 2021. Eichholtz, Korevaar, Lindenthal, 2012.

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**Title: Market and behavioral failures in the energy transition****Supervisor: Linde Kattenberg** ([l.kattenberg@maastrichtuniversity.nl](mailto:l.kattenberg@maastrichtuniversity.nl))

**Short text:** To limit global warming, the Dutch Government has set the goal to reduce greenhouse gas emissions to half the 1990 levels by 2030. Household energy consumption accounts for 13% of the national energy consumption, where almost all of this energy is generated with the use of polluting fossil fuels. In decreasing greenhouse gas emissions, increased energy efficiency of the building stock is therefore an important factor.

Despite technological progress and the ever-improving cost-benefit tradeoff of residential energy efficiency, widespread investment in energy efficiency improving retrofits of houses is not yet observed. The literature widely acknowledges the presence of an 'energy efficiency gap' between the levels of investment that are thought to be privately cost-effective and the lower levels of investment that are actually occurring.

A range of market and behavioral failures are named in the literature as possible explanations for this underinvestment. In this thesis, you will examine the attitudes and opinions of households towards the energy transition of the housing market, through survey results of a representative sample of Dutch households. You can explore what barriers exist, and how these differ for households with different demographic characteristics and housing situations. With your insights, you can reflect on the ambitions that the government set in the Climate Agreement, and give directions for future policy design.

**Data sources:**

- LISS 2020 survey: State of the environment and environmental policy

**References:**

- Jaffe, A. B., & Stavins, R. N. (1994). The energy-efficiency gap What does it mean?. *Energy policy*, 22(10), 804-810.

- Gillingham, K., Newell, R. G., & Palmer, K. (2009). Energy efficiency economics and policy. *Annual Review of Resource Economics.*, 1(1), 597-620.

Requirements: Requirements: Statistical proficiency, using R or Stata.

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**Title: Distributional effects of energy efficiency policies****Supervisor: Linde Kattenberg** ([l.kattenberg@maastrichtuniversity.nl](mailto:l.kattenberg@maastrichtuniversity.nl))

**Short text:** To limit global warming, the Dutch Government has set the goal to reduce greenhouse gas emissions to half the 1990 levels by 2030. Household energy consumption accounts for 13% of the national energy consumption, where almost all of this energy is generated with the use of polluting fossil fuels. In decreasing greenhouse gas emissions, increased energy efficiency of the building stock is therefore an important factor.

A cost effective way to realize a large gain in energy savings is by retrofitting houses that are currently characterized by the lowest energy efficiency. In this thesis, you will analyze survey results of a representative sample of Dutch households that include questions on living conditions, and on demographic characteristics of the tenants. You will identify the features of households that live in houses with poor energy efficiency. What are their characteristics and how can barriers towards energy efficiency investment be overcome? What do the characteristics of these households mean for the distributional effects of the energy transition? Which households carry the largest burden of the energy transition, and what does this imply for the design of (redistributive) energy efficiency policies?

**Data sources:**

- Household survey data, for example Housing section of LISS panel.

**References:**

- Allcott, H., Knittel, C., & Taubinsky, D. (2015). Tagging and targeting of energy efficiency subsidies. *American Economic Review*, 105(5), 187-91.

- Borenstein, S., & Davis, L. W. (2016). The distributional effects of US clean energy tax credits. *Tax Policy and the Economy*, 30(1), 191-234.

- Santamouris, M. (2016). Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change. *Solar Energy*, 128, 61-94.

Requirements: Statistical proficiency, using R or Stata.

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**Title: Global pension fund investment performance in real assets like commodities & other real assets (e.g. agriculture)**

**Supervisor: Alexander Carlo** ([a.carlo@maastrichtuniversity.nl](mailto:a.carlo@maastrichtuniversity.nl))

**Short text:** Maastricht University's Finance Department works together with CEM, the leading global database regarding pension fund investments. CEM have shared their entire investment database, mapping the investments of about 1,000 pension funds worldwide for the last 30 years. This database is a research treasure, and CEM allows a selected group of students to do research with it under the guidance of Maastricht University professors Eichholtz, Kok and PhD candidate Alexander Carlo.

This topic focuses on the factors causing differences in investment allocation, cost and performance for commodities & other real asset investments by pension funds. Think of issues like country of origin, investment style, pension fund size,.... Are performance differences between pension funds persistent? How do cost levels relating to commodities investment differ across the globe and over time? Are advantages to scale important in cost levels? Have costs come down after the crisis? What is the role of investment style (internal, external, fund-of-funds, REITs) in the cost levels experienced by pension funds?

**Data sources:**

- CEM data.

**References** and background reading:

The thesis can be inspired by papers that previously used the CEM data, e.g.

Andonov, Eichholtz & Kok (2015, *Journal of Financial Markets*) and Andonov, Eichholtz & Kok (2013, *Journal of Portfolio Management*).

Andonov, Kraeusl & Joshua (2021, <https://dx.doi.org/10.2139/ssrn.3245543> ).

**Requirements:**

- Statistical proficiency, using R.

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**Title: Pension fund commitment to ESG principles**

**Supervisor: Alexander Carlo** ([a.carlo@maastrichtuniversity.nl](mailto:a.carlo@maastrichtuniversity.nl))

**Short text:** Maastricht University's Finance Department works together with CEM, the leading global database regarding pension fund investments. CEM have shared their entire investment database, mapping the real estate investments of about 1,000 pension funds worldwide for the last 30 years. This database is a research treasure, and CEM allows a selected group of students to do research with it under the guidance of Maastricht University professors Eichholtz, Kok and PhD candidate Alexander Carlo.

This topic focuses on mapping pension fund names in the CEM database to publicly available data about these pension funds, particularly from an ESG perspective. For example, the student can collect data on which pension funds in the CEM database are signatories to the United-Nations Principles for Responsible Investment (PRI). Or: collect data on board structure to understand the diversity of pension plans. After collecting this data, the next step would be to empirically estimate a model that looks at determinants of becoming a PRI signatory, of board diversity, etc. For example, think of variables like plan type (public vs private), country of origin, investment cost levels, investment style, pension fund size, etc.

**Data sources:**

- CEM data.

- PRI data



**References** and background reading:

These studies have extensively used the CEM database before:

Andonov, Eichholtz & Kok (2015, Journal of Financial Markets) and Andonov, Eichholtz & Kok (2013, Journal of Portfolio Management).

Other related literature: Peillex, J., & Comyns, B. (2020). Why do financial companies adopt the United Nations Principles for Responsible Investment? Accounting Auditing Control, 26(1), 79-117.

**Requirements:**

- Statistical proficiency, using R.

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**Title: Benchmark shopping behavior for global pension fund real estate investments**

**Supervisor: Alexander Carlo** ([a.carlo@maastrichtuniversity.nl](mailto:a.carlo@maastrichtuniversity.nl))

**Short text:** Maastricht University's Finance Department works together with CEM, the leading global database regarding pension fund investments. CEM have shared their entire investment database, mapping the real estate investments of about 1,000 pension funds worldwide for the last 30 years. This database is a research treasure, and CEM allows a selected group of students to do research with it under the guidance of Maastricht University professors Eichholtz, Kok and PhD candidate Alexander Carlo.

This topic focuses on whether global pension funds engage in benchmark shopping behavior, when it comes to reporting the benchmark-adjusted performance of their real estate investments. Performance measurement of less-liquid, non-traded assets is challenging, especially at the point of benchmark selection. This implies that managers have a lot more discretion in the benchmark selection procedure, which opens the door for agency problems. Previous studies by Ludovic Phalippou have documented that private equity buyout funds engage in strategic benchmark selection, by selecting and switching between benchmarks in order to claim outperformance. If you choose this thesis topic, you will study whether this behavior can also be observed for the real estate asset class. The first step is to map all the different benchmarks used by the global pension funds in the CEM database. Finally, you will apply empirical models to analyze determinants of engaging in this benchmark shopping behavior. For example, think of variables like plan type (public vs private), country of origin, investment cost levels, investment style, pension fund size, etc.

**Data sources:**

- CEM data.

**References** and background reading:

These studies have extensively used the CEM database before:

Andonov, Eichholtz & Kok (2015, Journal of Financial Markets) and Andonov, Eichholtz & Kok (2013, Journal of Portfolio Management).

Phalippou, L., An Inconvenient Fact: Private Equity Returns & The Billionaire Factory (2020). University of Oxford, Said Business School, Working Paper, Available at SRN: <https://ssrn.com/abstract=3623820>

Phalippou, L., 2014, Performance of buyout funds revisited?, Review of Finance 18, 189–218.

**Requirements:**

- Statistical proficiency, using R.

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**Title: Explaining Indoor Air Quality: A Behavioral Study**

**Supervisor: Xudong Sun** ([x.sun@maastrichtuniversity.nl](mailto:x.sun@maastrichtuniversity.nl))

**Short text:** The air that we breathe inside and outside buildings has implications for physical development, cognitive performance, and overall productivity, and the body of evidence on this topic is increasing rapidly. Intuitively, indoor air quality (IAQ) is more

likely to be immediately affected by various occupant behaviors such as entering/leaving the room, opening/closing windows, using air conditioning, working on various work types/workloads, and more possible activities we might find in the future. Meanwhile, such behaviors are affected by both indoor and outdoor environment quality. A better understanding of the dynamics between occupant behavior and IAQ could help us develop a holistic view on green building topics.

This thesis aims to examine the relationship between occupant behavior and indoor air quality by combining data analytics and field studies. We use sensor-based data for IAQ measurements, and use a combination of motion sensors and field studies to collect behavioral data. We plan to firstly establish a mapping between certain behaviors and IAQ measurement patterns, then quantify the correlation between them.

**References** and background reading:

Lin, Beiyu, et al. "Analyzing the relationship between human behavior and indoor air quality." *Journal of Sensor and Actuator Networks* 6.3 (2017): 13.

Hua, Ying, Özgür Göçer, and Kenan Göçer. "Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building." *Building and Environment* 79 (2014): 124-137.

**Requirements:**

1. Statistical proficiency;
  2.
    - a. Experience of field study in the Netherlands preferred, or,
    - b. Programming-based workflow preferred (R, Python, Matlab, or Julia)
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**Title: Open the Black Box: Interpretable Deep Learning Methods for Indoor Environment Quality Studies**

**Supervisor: Xudong Sun** ([x.sun@maastrichtuniversity.nl](mailto:x.sun@maastrichtuniversity.nl))

**Short text:** Deep learning has gained promising results in many fields. However, most neural network-based algorithms lack interpretability, which limits most deep learning methods to "applied" methods instead of insights or theories. Recent findings on interpretable convolutional neural networks (CNN) has shed light on the question of what neural networks learn by matching network layers with image patterns.

In this thesis, we will build a series of forecast models for sensor-based indoor air quality (IAQ) measurement data using Temporal Convolutional Networks (TCN), which is a special 1-dimensional form of CNN. In this process, we will test network structures that can be interpreted as patterns, which will be matched with occupant behaviors. A better understanding of the dynamics between occupant behavior and IAQ could help us develop a holistic view on green building topics.

**References:**

Pantiskas, Leonardos, Kees Verstoep, and Henri Bal. "Interpretable Multivariate Time Series Forecasting with Temporal Attention Convolutional Neural Networks." *2020 IEEE Symposium Series on Computational Intelligence (SSCI)*. IEEE, 2020.

Zhang, Quanshi, Ying Nian Wu, and Song-Chun Zhu. "Interpretable convolutional neural networks." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 2018.

Shih, Shun-Yao, Fan-Keng Sun, and Hung-yi Lee. "Temporal pattern attention for multivariate time series forecasting." *Machine Learning* 108.8 (2019): 1421-1441.

**Requirements:**

Knowledge in deep learning (especially convolutional neural networks)  
Experience in at least one deep learning platform (TensorFlow/Keras preferred)  
Programming-based workflow required (Python, or something better), **or**,  
Your motivation and capability that makes you learn all above in 2 months.

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**Title: Evaluating the Effect of Indoor Air Quality on Commercial Office Markets**

**Supervisor: Xudong Sun** ([x.sun@maastrichtuniversity.nl](mailto:x.sun@maastrichtuniversity.nl))

**Short text:** Does indoor environment quality (IAQ) affect commercial real estate value? There is convincing evidence that there is a premium in rental rates and sales price for green office buildings with eco-labeling such as Energy Star or LEED. Meanwhile, studies show that occupant productivity/performance is significantly affected by indoor air quality (IAQ) and other environmental features. Does the premium of green office buildings a result of better occupant productivity, eco-labels, or a combination of the two? This thesis aims to quantitatively evaluate the relationship between IAQ and the market value of office real estate.

**References:**

Eichholtz, Piet, Nils Kok, and John M. Quigley. "The economics of green building." *Review of Economics and Statistics* 95.1 (2013): 50-63.

Fuerst, Franz, and Pat McAllister. "Eco-labeling in commercial office markets: Do LEED and Energy Star offices obtain multiple premiums?." *Ecological Economics* 70.6 (2011): 1220-1230.

Al Horr, Yousef, et al. "Occupant productivity and office indoor environment quality: A review of the literature." *Building and environment* 105 (2016): 369-389.

Thermal and IAQ effects on performance (<https://www.researchgate.net/project/Thermal-and-IAQ-effects-on-performance>)

**Requirements:**

Knowledge in real estate asset pricing; Statistical proficiency; Experience in data collection and analytics