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THE CONTEMPORARY DPW MODEL FOR THE COMMERCIAL REAL ESTATE SECTOR AND ITS ANALYTICAL CAPABILITIES

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ABSTRACT

This paper presents an adjustment of the classical DPW model, which includes two different interest rates and the secondary market in the commercial property market. Separating the mortgage rate from the discount rate helps to understand why not all investments which seem to be profitable are carried out. If the discount rate is much higher than the mortgage rate, the risk will prevent investors from entering this investment. In the longer run, the stock will depreciate, and the equilibrium amount of commercial space will decline. The other important point is the consideration of the secondary market, through which investors exit the market when profitability declines. Also the inclusion of a demand curve in the primary market and accounting for the fact that developers in the CRE market are mainly price or cost takers helps to understand our observations what we observe in the real world, much better.

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1. Introduction

The commercial property market has evolved in Europe and in other countries during the recent years, mainly driven by a stable economy and historically low interest rates. The recent COVID pandemic in 2020 and the Russian war in Ukraine in 2022 have, however, shaken the fundamentals. Łaszek et al. (2024) describe those events in the residential property market as multi-cycles. A similar pattern could be observed in the European commercial property investment market. Transaction volumes rose during 2011-2019, decreased slightly during the COVID pandemic in 2020 and grew again, but slumped when the ECB increased the interest rates in late 2022 (see BNP Paribas Real Estate, 2024, p. 13). The demand for office space has also changed due to the pandemic, as remote work started to be a significant form of employment (see Gupta et al., 2022). A similar change could be observed in Poland. While the residential real estate market remained initially unaffected (which Augustyniak et al., 2021 explain in detail), the rise in interest rates already had an impact on the commercial property market (see Łaszek et al., 2024). The commercial property sector in Poland was also affected. It is strongly connected with the European market, both due to the significant share of foreign financial institutions and investors, as well as due to the connections of the firms that rent commercial property. In the office sector, rents are usually denominated in euro, with a large share of mortgages also being in euro. This paper aims to provide an augmentation of the classical DiPasquale and Wheaton (1992) model to explain, in more detail, what happened in the commercial property market in Poland, with a focus on the office market in Warsaw.

The classical four quadrant model was developed by DiPasquale and Wheaton (1992) to combine the space market for commercial real estate with the market of objects (buildings). If people want to rent more space, rents go up, and through the financial market (discounted cash flow from rents), other people are willing to pay more for owning or constructing new buildings for rent. If this amount exceeds the construction costs, people order more buildings, developers deliver new buildings with a delay and the stock increases.

The DiPasquale-Wheaton (DPW, hereafter) model is a great tool for academic considerations (see Achour-Fisher, 1999; Lisi, 2015) and for further empirical research (Colwell, 2002). The original model has three important features. It shows that an increase in demand

for space leads to a strong increase in demand for new construction. But as construction is slow and new construction accounts for a small fraction of the whole stock, the adjustment is slow. Secondly, the model incorporates what is known as the financial accelerator (see Bernanke et al., 1999), i.e., even small changes in the interest rate lead to strong changes in the valuation of property through the discounted cash flow model and can lead to a property price boom. Finally, the model includes the fact that real estate depreciates, so there's always a given amount of construction needed to maintain a constant real estate stock.

In this paper, we introduce and combine three important features. The first is the use of different interest rates: one interest rate for mortgages, one that covers the debt service and a different interest rate for the discounting of the cash flow by the investor or the financing bank. This can generate multiple equilibria in the market. The property market is strongly connected to the financial market, which depends on the available financial instruments and related interest rates. The main interest rates that are connected to the real estate market are those affecting the financing and valuation of real estate, and are related to the interbank rate and the government bond rate. The interest rate that is determined on the financial market is the cost of capital, which measures its productivity. Usually when capital is abundant, its marginal productivity is low and so is its cost, measured by the interest rate. There are many factors which shift the interest rate from its equilibrium level, like inflation or the occurrence of a crisis. The commercial bank which finances the investment is an intermediary that takes money from the financial market and supplies it to those who want to invest in real estate. When investors or banks valuate a property, they consider the discount rate as a starting point, which, under current and expected business conditions, consists of the risk free rate and a markup to cover the risk of the real estate investment. Such a discount rate is used by the investor to evaluate the price of the property at which he could sell it to other investors. Also the bank wants to know the price it could obtain without a loss in case the investor defaults. The markup that the bank sets above the interbank interest rate should cover the current mortgage risk, whereas the downpayment from the investor will be used to cover the recovery costs (the loan to cost or loan to value ratio does not usually exceed 80%). On the market, one can also find other indicators, which are related to the property price, rental income and the mortgage interest rate, that take into consideration the profitability (ROE) and liquidity of the sector (DSTI - debts service to income ratio).

Secondly, the model also includes the secondary market. In the original model, excessive supply will vanish in the long run through depreciation. But in reality, investors want to exit the market and will therefore put their property on sale on the secondary market. This will dampen transaction prices and, in consequence, has important implications for the construction sector.

Thirdly, the augmented model incorporates the fact that the construction costs do not depend only on the construction volume in the commercial property market, but also on housing construction and construction in the civil engineering sector. This allows one to estimate a new supply curve, which shifts due to changes in the whole construction sector. Including those extensions in the model helps us to better understand what we observe in the real world.

2. Material and methods

The classic DPW model was created as a generalization of the commercial real estate market. Its novelty in relation to simple market models was the separation of the property market (real estate capital) from the space markets (rent, services) as well as combining them into a whole economic system by means of the interest rate and the financial capital market, which valued real estate (physical capital) using the income method on the basis of the value of their services and was the main regulator of the state of their resources and production.

The DPW model is a very good macroeconomic and didactic model explaining, in a relatively simple way (four quadrants), the de facto basics of the functioning of capital as a factor of production and capital markets in the economy (physical capital, physical capital services in the production of net value, financial market, interest rate, financial capital). This was probably not the main goal of the authors, but it is helpful in teaching macroeconomics. Consequently, it can do well to explain real estate markets, which are one of the forms of capital that usually dominate the sector as a factor of production over land and labor in the process of producing real estate services, and which are very capital intensive.

The separation of the market for capital objects and the market for capital services is an economic fact and a classic way of analyzing capital as a factor of production. The same is true of the financial market, which is coupled with the capital market and values assets, as well as enabling the financing of capital

investments in an indirect form, i.e., debt or equity instruments, as long as they provide adequate cash flow. As a consequence, investments through financial instruments make the structurally low liquid capital market a liquid market.

From the point of view of the real estate sector, by introducing two real estate markets (capital and its services), the financial market and elements of sectoral circular flows of resources, this model primarily explains commercial real estate markets, i.e., income generating real estate, including residential real estate for rent. The construction of the model, in which transactions and production volumes are based on valuation, means that there is no room for the malfunction of the development market, overproduction, price booms and subsequent shocks. Changes in equilibrium levels are a consequence of changes in external economic parameters such as incomes, costs and interest rates, and adjustments take the form of increases in production and the resource, or its decrease and depreciation of the resource. Consequently, the model describes a long-term equilibrium, which could be described as long-term supply adjustments. Shocks are possible only in the rental market, because the stock is inelastic in the short term.

The classic model occupies four quadrants (see Figure 1), the first of which is the production of real estate services (for consumers or businesses), the second is the financial sector, which in the model values the value of capital based on the obtained revenues (net rents) and the discount rate. In the third quadrant, developers make production decisions based on the market valuation of the capital value and the cost curve, and the financial sector decides on the allocation of capital to the real estate sector. In the fourth quadrant, the final amount of real estate capital in the sector is determined by deducting its physical depreciation and adding new physical investments to the existing stock.

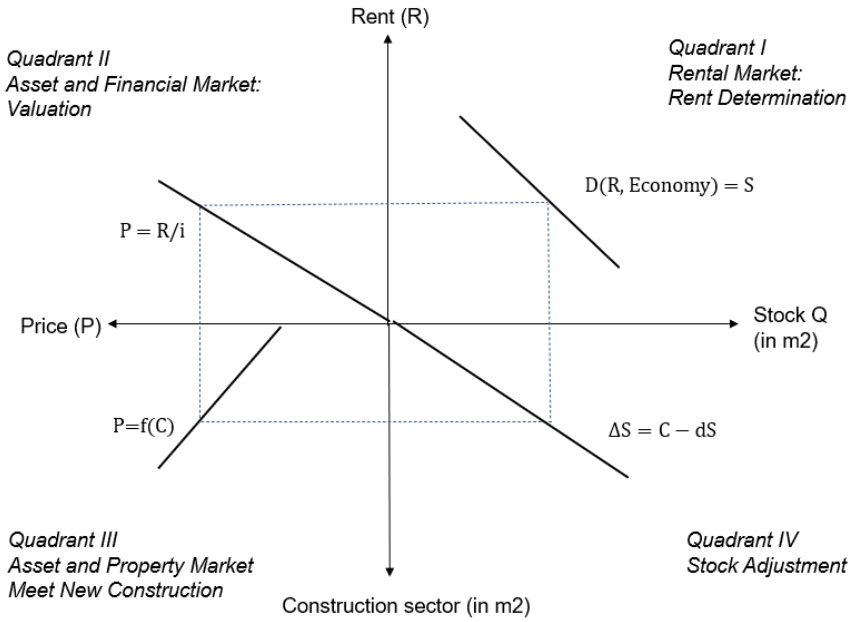


Fig. 1. Classical DPW model. *Source*: DiPasquale and Wheaton (1992). The names of the quadrants were updated by the author.

The main mechanism of the model are changes in demand for space in the first quadrant and changes in the discount rate, which is related to interest rates and the financial cycle. An increase in demand for space increases the level of rents, which, with a rigid supply, results in an increase in the market value of real estate above production costs. The demand for space is described by the equation D (R,Economy) = S, where the demand (D), which is the result of rents (R) and economic variables, has to be in line with the current supply (S). The equilibrium rent level can be discounted by the discount rate, and one obtains the equilibrium price (P =R/i, where P is the price, R the rent level and i the discount rate). In cases there is excess demand for space, rents grow. As a consequence, investors are willing to pay more for new objects, development becomes profitable (the price P is equal to the new construction costs P=f(C)) and, through new construction, the real estate stock grows. Ultimately we obtain a new level of equilibrium with a higher stock Q. Finally, in quadrant IV, we observe the adjustment of the stock S. The stock changes (ΔS=C−dS) due to new

construction C and the depreciation of the stock dS. A decrease in rents (due to lower demand), however, results in the decrease in the profitability of new investments, leading to less construction and the depreciation of the stock. A similar effect is caused by changes in the interest rate, which affect the increase or decrease in the market value of objects and trigger the same mechanism.

However, when trying to apply the model to the analysis of the modern commercial real estate market, we come across significant problems and propose an augmentation of the model to solve them:

1. The design of the classical DPW model (space market and market for new construction) does not allow for the generation of short and asymmetric shocks and cycles on the market of new facilities, which are characteristic of the modern commercial real estate sector. The model does well to explain longer changes in the market, because growing demand meets a rigid supply and leads to higher rents and, consequently, to higher prices. Those make investing more attractive and new construction starts to grow. We can finally observe an oversupply of space and effects that are similar to the Cobweb model. However after including the demand curve in the primary and secondary market, we can also explain short term shocks. When demand for space declines, or when investors want to exit the market, they put facilities on the secondary market. This generates price pressure for newly constructed buildings and can cause a collapse of prices and valuations on the entire market. We therefore include the secondary market in the augmented model.
2. Real estate markets are based on external capital and financial leverage. As a consequence, risk, financial instruments and business expectations are diversified, which leads to the differentiation of discount rates and the cost of capital. In the original model. there is only one interest rate, but we propose to apply two different interest rates (one for mortgages, one for discounting the cash flow). The mortgage rate is the sum of the inter-bank interest rate, the bank mark-up and the repayment of the principal. The financing institution (e.g., bank) discounts the cash flow with this rate to assess the maximal amount of mortgage it could offer to the investor. The mortgage rate covers the general risk for the bank. There are different banking systems and regulations around the world, therefore this mortgage rate can vary. In fact, the bank is a financial intermediary and wants to minimize credit risk; therefore, it applies limits like the loan-to-cost ratio (LTC) and the debt service-to-income ratio (DSTI), as well as other prudential measures. The mortgage rate, however, does not cover the project risk. To tackle this problem, the bank applies a discount rate, which can be the same as the one that professional investors apply. It is usually higher than the mortgage rate, covers part of the project risk and market risk, and is used to assess the market value of the property by discounting the cash flow. Introducing those modifications, we implement the common fact that the financial sector takes into account the risk of financing commercial property and tries to minimize it. The reality is more complicated and Brown and Matysiak (2000) devoted a significant part of their book to explaining how investment risk should be measured and incorporated in the valuations. Further on, Brueggeman and Fisher (2022) show that the discount rate also depends on the time horizon of the investment. Nevertheless, for simplicity we apply one discount rate that is applied by the investor for every horizon.

To sum up, the contemporary DPW model loses its character of a long-term mechanism that relatively gently matches demand to supply in favor of a model controlled by shocks on individual markets, which helps to explain what is observed in the real estate market.

The main changes compared to the classic original are:

1. Addition to the primary market of objects (PM) the secondary market of objects (SM). This captures the fact that the assets increase through higher prices and new construction, while investors exit the market through the secondary market and price drops are possible.
2. Adding demand curves in both property markets. This means that the price of an object (asset) is a price that clears the market, and in conditions of supply shocks, transactions will take place on the basis of the relationship of scarcity and not the value calculated using the income method.
3. Inclusion of multiple interest rates as discount rates. The interest rate is the long-term price of capital, so its value decreases with the accumulation of capital over the long run. The current interest rate is deflected by the central bank's monetary policy (financial cycle), which, together with fiscal policy, as the so-called policy mix, is the basic tool for influencing the economic situation through the

government and the central bank. In an economy without a central bank, it is deflected by the demand for capital changing in the cycle, which works similarly to the case with a central bank, only in a more chaotic way. Theoretically, for long-term valuations, the discount rate should follow the interest rates, which are expected to fall as the capital stock in the economy is growing. However, since the future is always risky, longer rates are generally subject to a higher risk premium, resulting in a classic positive yield curve slope. As a consequence, the interest rates expected and implemented by the investor and the willingness to leverage investments will also vary. A business investor will expect higher returns and higher risk, so they will tend to leverage higher. This decision will also be influenced by the tax and prudential regulations of financial institutions.

3. The importance of the financial market and financial instruments in the contemporary DPW model

3.1. Financial market functions in the modified DPW model

In contrast to the classic DPW model, where the financial market only valued the value of projects, in the modern model, it is essentially the basic market determining the liquidity of the real estate market. It can be assumed that it will be similar to an efficient market, i.e., it will disseminate available information, although this condition does not have to be met in the real estate market. This market operates on the basis of financial instruments, and the basic parameter is interest rates and risk premiums imposed on individual financial instruments. This market fulfills the following key functions in the commercial real estate sector:

- the market evaluates the risk and expectations of investors related to the commercial real estate sector and premiums imposed on interest rates in sectoral financial instruments,
- evaluates projects from the investment point of view (turnover) and security of pledge for mortgage, bank and equity financing,
- values equity securities (stocks, shares) related to the project and visualizes capital gains related to the leverage and commercialization of the project,
- the market arranges equity financing,
- the market organizes financing with borrowed capital (credit instruments, mezzanine finance, equity instruments) and evaluates related financial instruments.

In macroeconomics, the interest rate for the economy determined by the market or the central bank is a key macroeconomic parameter. A prediction of the interest rate in the long run, which is important for the real estate market, is not easy. Theoretically, this interest rate is the price of capital, regardless of its form (financial or real) and allows time to be taken into account in economic calculation, as well as the transition between a resource and a periodic cost understood as financial flow. The percentage is calculated as an actual cost or as an expense imputed on equity. It is a real cost and flow, and its source in macroeconomic terms is the added value generated by physical capital. In microeconomic terms, i.e., in the project efficiency calculation, the rate is a measure of the effectiveness of the project measuring the effect to the inputs. In real estate science, instead of the classic interest rate or profit rate, the term return (yield) is often used, which means the ratio of profit increased by depreciation and related to the capital expenditures incurred. Therefore, this category does not take into account operating costs, which are calculated and covered separately (the so-called gross and net rent), which makes it similar to the interest rate, but it does include in the numerator depreciation costs, which are not a net value, but a value carried over from previous periods. This inconsistency of the account and its complication results from the fact that the depreciation of the capital good is an accounting expense and not an expense until it is liquidated and replaced. However, this difference should be remembered when we use measures based on rates of return and compare them with classic interest rates, because the former give nominally higher results than those based on profit rates, precisely because of the depreciation added to the profit.

In the short term, when markets, including the capital market, are not balanced, the interest rate often breaks away from these fundamentals, becoming the price of liquidity represented by money (the price of money when demand collapses and a liquidity trap occurs) and related to the financial market, or vice versa, showing an imbalance in the capital market (large supply of savings, lack of demand, including for capital, due to disruptions in circular traffic in the economy). The rate affects virtually all financial instruments, while the basic financial instruments using interest rates are loans, especially investment loans, which convert financial capital in the form of savings into real capital. However, since there are many

different financial instruments in modern financial markets with varying risks, maturities and flows, their interest rates will vary.

In the modern economy, the interest rate affects not only investment outlays, but also consumer demand, being a component of consumer loans, especially long-term loans, including mortgages. In this case, it is usually the price of capital producing consumer services and is transferred to their price, but it can also directly finance pure consumer spending.

Since the accumulation of capital, i.e., changes in its supply, proceed slowly, the interest rate, as the price of capital, should also be quite constant over time. In reality, however, cyclical changes in the market situation affect cyclical changes in the demand for capital, which causes natural market volatility of interest rates, i.e., declines in downturns and increases in high economic conditions. The second premise of the financial cycle is the state's countercyclical policy, which works in a similar direction, but tries to be *ex ante* and not *ex post*. Nowadays, the interest rate is, next to fiscal policy, the basic instrument for controlling the economy, i.e., aggregate investment and consumption demand. It is aimed at increasing demand in periods of weaker economic conditions (interest rate cuts) and its reduction (interest rate increases) in high economic conditions, thus strongly affecting the real estate sector in an intentional or often unintended way. Therefore, the interest rate differentiates as a function of the maturity of the financial instrument in the same period (the so-called yield curve), because knowing the cyclical nature of interest rates and its current level, attempts are made to forecast future phases of cycles and changes in interest rates depending on the maturity of the instrument. The other reason is the unknown risk, which grows over time.

The real estate sector is sensitive to changes in interest rates due to the high involvement of external financing, especially in the form of mortgage loans, which, due to the long maturity and high share of interest cost in the loan installment and the low level of interest rates in recent years, cause shock reactions in cash flows even with small interest rate increases. The second type of shock occurs with inflation increases. Including inflation in interest rates, as opposed to indexing loans, quickly causes the so-called payment tilt, i.e., the accumulation of loan repayments at the beginning of its course, which often leads to mass insolvency of borrowers. The impact of inflation on the real estate market is more complex and beyond the DPW model, as it depreciates debt creating extraordinary capital gains while leading to higher interest rates and the discussed payment tilt effect.

The second, no less important, channel of the interest rate is the valuation of real estate capital. Periods of economic downturn and low interest rates result in lower expectations related to business profitability, but higher valuations of assets. With later increases in interest rates the value of collateral decreases again and problems for the banking sector emerge, limiting its ability to grant loans. However, the main problems will be related to previously granted loans, the value of collateral of which will deteriorate, forcing banks to create provisions for future losses. Valuations are therefore cyclical, and this affects both existing and new projects.

3.2. Interest rates in the model

The development of the financial market and the heterogeneity in the real estate sector means that its basic parameter, which is the interest rate, cannot be unified to a single, universal size. This is only possible in aggregated macroeconomic models or theoretical models of efficient markets. When moving to meso-economic and sectoral models, it becomes necessary to make the model more realistic and introduce more financial instruments and related interest rates. This also applies to the sectoral DPW model in its classic form and causes one discount rate for mortgage and valuation purposes to cease to be sufficient, even in textbook terms. Financial instruments on the modern real estate market are usually equity instruments and financial instruments that enable project financing in various ways. In the case of the real estate market, hedging instruments against the risk of physical events (like fire) and financial risk, from the debtor's insolvency to cash flows on the debt instrument, are also important. In some systems or transactions, they are a condition for the issuance of equity or debt instruments, especially derivatives created on these instruments. Borgersen and Emblem (2022) introduced three different interest rates in the owner occupied housing market model of DPW, and compared the resulting costs with an alternative rent. In this paper we focus on investors, so we need to focus on valuations which are the result of a discounted cash flow.

Similarly to residential purchases by private people, commercial property investments are also financed with mortgages. In the case of the latter however, especially due to gains that the tax shield creates (calculating interest on loans into costs), investors want to obtain the highest possible financial leverage. Those

instruments allow for an increase in the rates of return on equity to such an extent that real estate investments, which usually have only a low margin but bear a high risk, become profitable for the investor. By investing with leverage, the investor also reduces his own risk by being less involved in each single project and has the possibility of diversifying the investment portfolio. However, the consequence of high leverage is an increase in the sensitivity of projects to changes in interest rates, especially when there is a small difference between the rates of return on investment and interest rates. The investor expects the internal rate of return on real investments to be higher than the interest rates of the instruments financing these investments, because only then does he leverage his profits. Otherwise, the investor leverages his losses. Discount rates are usually higher than interest rates on loan instruments, which enables the use of leverage and commercialization of the project's equity securities. However, with a rapid increase in inflation, the situation is reversed, and projects are loss-making.

As a result, there are many discount rates on this market, the most important of which for explaining the modern DPW model are:

The discount rate, used to value a property by an investor, it is the interest rate expected by the investor based on his experience and expectations because of the undertaken investment. It depends on the business risk and the market situation as well as the opportunities (alternative profits) held by the investor. To achieve it, he must buy the asset at a price that is the product of the income earned and the expected rate of return. Since, according to the theory of efficient markets under comparable conditions, comparable businesses carry similar rates of return, the expectations of professional investors in this respect should generally be quite similar, which does not mean the same. Consequently, there is also a classic demand curve in this market. Often, due to its greater intuitiveness, instead of the discount rate, it uses the payback time (the inverse of the discount rate) and multiplies it by the projected profits.

The discount rate used for the valuation of the property by the bank should be the same as commercial property investors apply to valuate an investment. As a long-term rate containing risk premiums, it should be higher and more stable than the base rate set by the central bank. The bank should be more conservative and put a cap of 80% on the LTC, which is a precaution to get at least a significant part of the mortgage back, in case the investor gets into financial troubles and the value of the property declines.

The loan rate is the lowest cost of financing with borrowed capital on this market, as it does not cover the project risk, which is theoretically buffered by collateral. It may be the discount rate for small business, as the non-professional investor may treat his investment as if it were a loan for a business.

The expected return on equity of a professional investor investing equity in commercial real estate should be high due to alternative options. This expected return should be close to the risk-adjusted discount rate used in business, i.e., higher than the rate of return on projects and closer to the leverage rate on equity.

4. Functioning of the modified DPW model

4.1. Operation of the financial market in the modified DPW model

Due to its key importance, we start the analysis of the modified model with the financial market. The financial market in the model is presented as in the original model in Quadrant II; it is necessary to refer to Quadrants I (space market) and III (development market and secondary market) and IV (depreciation/ depreciation of the building stock) with long-term equilibrium, in Figure 2a.

The modified model incorporates three discount rates, the pure interest rate on a mortgage, the mortgage rate which includes the amortization of the principal and the usual discount rate that investors apply. To explain this modification in detail, we present a simple example of the Warsaw office market. For the calculations, we apply the rents and construction costs of a new office building (per square meter) presented by Narodowy Bank Polski (2024, p. 31). For the calculations of the mortgage cost, we apply the estimation of the mortgage interest rate in euro, presented in the Narodowy Bank Polski (2024) report. The mortgage interest rate consists of the EURIBOR3M rate plus the bank markup, which was estimated at around 3%, thus under the negative EURIBOR3M (around -0.5%) during the years 2015-2022, the effective interest rate on mortgages was 2.5%. We further assume, following Olszewski et al. (2024), that the annual amortization of the mortgage is 2% (it takes 50 years to fully amortize it) and the discount rate for the cash flow applied by market participants was set at 8.5%. Figure 2b presents a zoom into Quadrant II of the model.

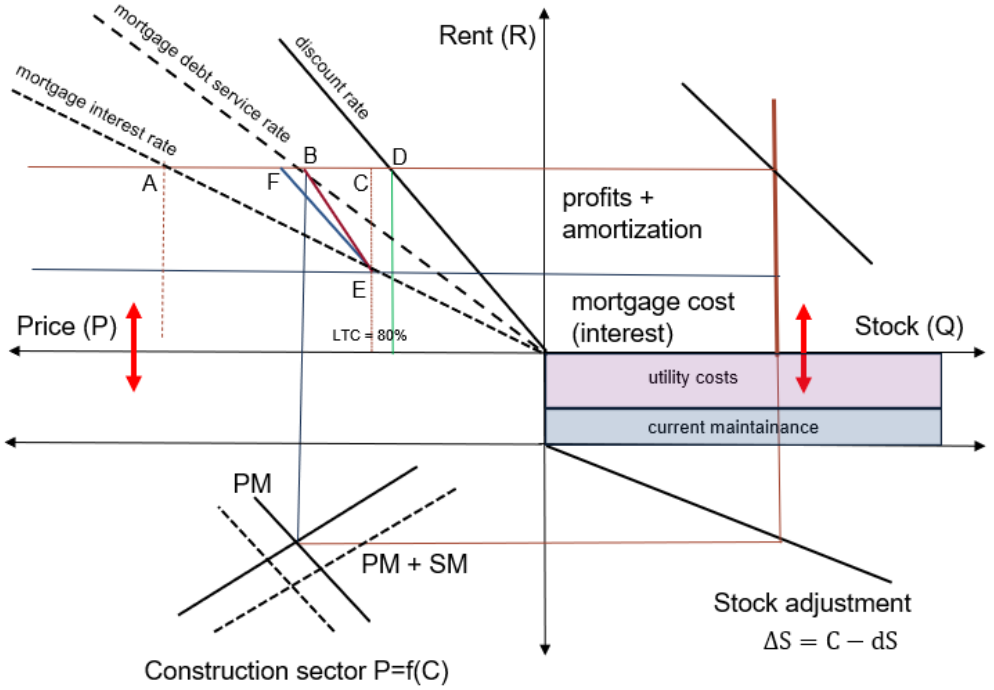
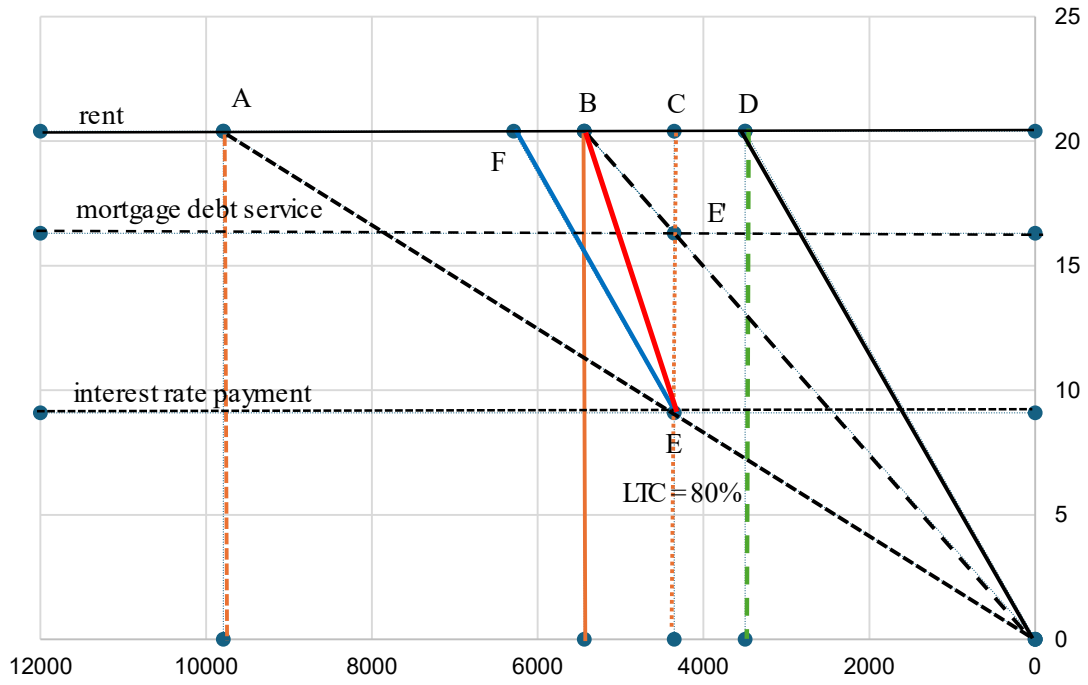


Fig. 2a. Modified DPW model and the functioning of the financial market. *Source*: own elaboration, based on DiPasquale and Wheaton (1992).



Note: The rent in euro per sq meter per month is on the y axis, whereas the value in euro per sq meter on the x axis.

Fig. 2b. Zoom into the Quadrant II of the modified DPW model and the functioning of the financial market. *Source*: own elaboration, based on DiPasquale and Wheaton (1992) and data presented in the NBP (2024, 2025) reports.

In the first step, the investor, through the financial market, makes a valuation of the planned project based on the cash flow it generates. Discounting the cash flow by the mortgage interest rate results in a value shown by Point A in the model. This amount is the mortgage availability of the investor, assuming he pays only the interest rate and pays the principal after selling the property in the future. To give an example, we take class A office rents from the Warsaw office class A market at the end of 2022, a time before interest rates increased

significantly. The monthly rent was 20.4 euro per month per sq meter, while the NOI is estimated as 80% of the net rent (as in Olszewski et al., 2024). The discounted cash flow (NOI) results in the following valuation: 20.4*0.8*12/0.025 = 7834 euro per sq meter. This is a theoretical point, because banks in Poland require a minimal amortization of the principal, usually 2%. The mortgage rate is therefore 2.5%+2% = 4.5%, and the calculation leads to the following valuation 20.4*0.8*12/0.045 = 4352 euro per sqm., which is marked as point B.

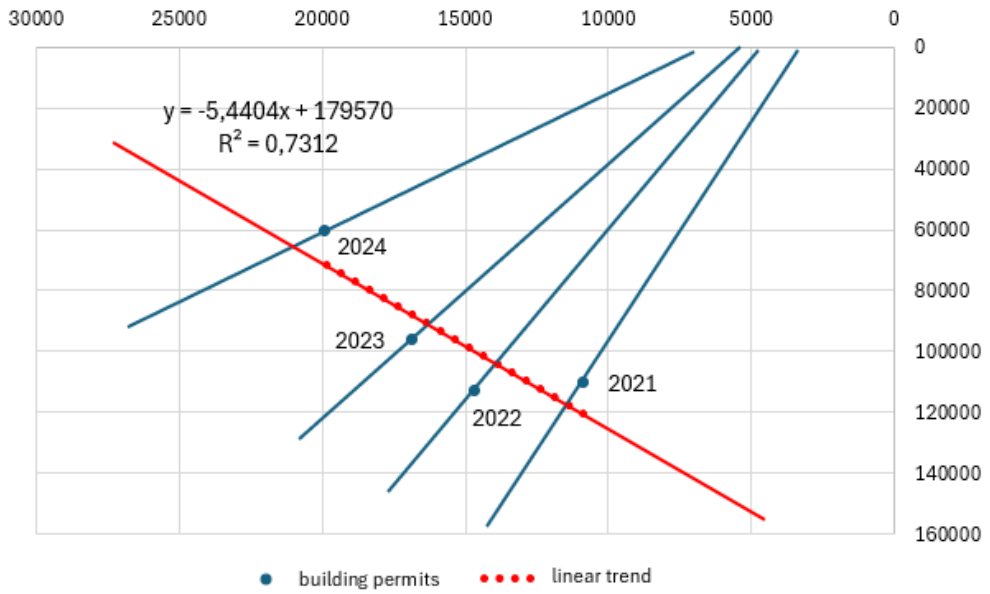
Such a valuation is higher than the bank valuation (point D of the model). The bank is only a financial intermediary, so it will minimize its credit risk by using a more conservative valuation in order to recover the borrowed funds throughout the course of the project and with changes in the market situation in the event of debt collection. The bank applies the discount rate that investors apply to value the property (8.5%), because this is the amount of money other investors would be willing to pay for the property in the event the initial investor has to sell it. The valuation in that case is 20.4*0.8*12/0.085 = 2304 euro. Banks want to grant large mortgages, so they will keep this number in mind, but stick to the previously estimated value. However, bank regulations usually put a cap on the loan-to-cost ratio at 80%, so the highest amount of mortgage that the bank is willing to give is 4352*0.8 = 3482 euro (point C in the model). Bank regulations also put a cap on the debt service coverage ratio, so that it does not exceed 80% of revenues. The discount rate applied by the bank and the resulting value of the project are generally not attractive in terms of business (which would be willing to pay more), but they can be a starting point for further financial considerations and the use of financial leverage that will improve returns on equity.

We can calculate the return-over-equity (ROE) of this investment. We assume a full occupancy and a tax rate of 19%, and for simplicity, ignore the tax shield and thus do not subtract the amortization of the building while calculating the profit. Only the interest payment is deducted from the rent income during the calculation of the tax. We assume that the LTC is 80% and the equity is 20%. The ROE of this investment is calculated as follows. The after tax income is (20.4*0.8*12 – 3482*0.025)*(1-0.19) = 81.12 and dividing it by the equity (4352*0.2 = 870,4), the ROE is 81.12/870.4 = 10.1%. The line between B and E and its angle show us the ROE of the investor. Finally, we can discount the NOI minus the interest rate with the market discount rate (20.4*0.8*12 – 3482*0.025)/0.085 = 136/0.085) which gives the value 1280 euro. This value is added to the value of the mortgage (point C) and results in point F in Figure 2b. What is important is the fact that this discounted cashflow is larger than the equity of the investor. He should be able to sell his own equity in the investment project with a profit, in case he decides to leave the investment at a slightly higher price on the market.

Also, Quadrant III of the augmented model in which new construction is explained needs to be discussed in some detail. In the original DPW model, there is only one curve, which relates new construction to construction prices and the current price. DiPasquale and Weaton (1995) explain that, in equilibrium, developers build that amount such that construction costs meet the current market price. They explain that construction costs rise with the construction volume. A production below equilibrium would result in excess profits, while too much construction would mean losses. We agree with this in general, but want to stress two things. The construction of office space accounts to a small fraction of general construction, so we can assume that those developers are cost takers to a large degree. Still, scarcity of land will increase construction costs. To understand the inclusion of a demand and supply, we apply data about the construction prices from the NBP (2024, 2025) reports and the volume of building permits (in sq m) in the last four years (the years are shown in Figure 2c). We estimate a linear demand curve and find that, as usual, demand (here for new construction permits) declines when construction costs increase. The supply curve can be estimated in a simple way. We know that it has to go through the volume of construction permits and through the zero line. We assume that when only the costs of construction land are covered, the developer constructs exactly zero sq m. When the price rises, more and more office space is constructed. During the recent four years, we observed that construction costs shifted upwards, while demand for new space (in terms of new construction permits) declined. It becomes obvious that, with only the original replacement cost curve, shocks are difficult to explain – the market always moves towards an equilibrium. Contrary, in the new model, a sharp increase in construction costs declines demand for new construction, which might shift demand towards the secondary market, on which office buildings from the existing stock are traded.

4.2. Operation of the property market (III Quadrant)

In the classic DPW model, there is basically no facility market understood as a place where new facilities are commercialized and introduced, and where facilities from the existing stock are rotated and restructured. New development facilities are introduced to the market at a value that coincides with the valuation when the demand for capital services increases, causing rents and prices to rise above equilibrium levels. There is also no secondary market for these facilities, which means that the facilities exit the market through depreciation, without an impact of such a situation on the property market. In the long term, such an assumption is acceptable, because long-term changes in the real estate stock are important. However, the abandonment of the secondary market and the classically understood primary market (supply, demand, price) makes it impossible to analyze short- and medium-term changes, which are the main problem of this market.



Note: The construction price in euro per sq meter is on the y axis, the volume of construction permits in sq meter on the x axis.

Fig. 2c. Zoom into Quadrant III of the modified DPW model – new construction. *Source*: own elaboration, based on DiPasquale and Wheaton (1992), construction costs: Narodowy Bank Polski (2025), construction starts: Statistics Poland (2025).

In the modern model, there is both a primary and a secondary market for these facilities. There is arbitrage between these markets, which is why the model assumes, for the sake of simplicity, the same equilibrium price for qualitatively (hedonically) similar facilities. Both markets do not work perfectly and deviations from the uniform price are possible. It was also assumed that transactions do not take place at the uniform price derived from valuation, but that there are classic shapes of demand and supply curves because of looking for bargains on the demand side (cheaper purchase) and emergency situations (selling at a lower price than valuation) on the supply side. The primary market (construction of new facilities) functions very similarly to the classic model. In the classical model, an increase in the valuation value above current production costs causes an increase in profits from the sale of facilities and, consequently, an increase in their production until the increase in costs causes the extraordinary profit to disappear. It is therefore the market that is responsible for the increase in real estate resources in both the classic and modern models. In the modern model, an increase in the valuation value is only one of the premises for an increase in demand, which appears as a classic, descending line. In the classic model, however, there is no secondary market, i.e., a place where existing entities exit the real estate market, and which can serve as a second indicator of the economic situation in the sector. When objects in the sector are put up for sale on the secondary market, prices can fall. This aspect of the model – the links between the space market and the facility market – has not been discussed in depth in the analyses but is an important element of the real estate cycle mechanism. The disproportions between the size of the stock market and the property market mean that small

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changes in demand for the resource generate subsequent cycles on the property market, especially new ones during the boom period and the so-called second-round effects with forced supply, the effect of falling income or credit problems.

4.3. The space market (Quadrant I) and the mechanism for regulating the amount of space (Quadrant IV)

The space market works basically in the same way as in the classic model. An increase or decrease in demand for space with its short-term rigidity causes rents to rise or fall, which translates into the profitability of the production of new facilities. When the price falls below the cost of reproducing the resource, this leads to its depreciation and activates the mechanisms of rent and construction growth until the equilibrium level is reached. After some time, rents start to fall and a new level of equilibrium will be reached. What can be improved further in the new model is to consider the currently higher vacancy rate and take it into account as a permanent element of the market.

5. Model response to shocks

The main problem with modern real estate project financing is the financial cycle and the related changes in interest rates. The case of an increase in interest rates on the market should be considered in relation to two situations and four scenarios: concerning projects already existing on the market and projects being designed, as well as broken down into the effects of an increase in real and nominal interest rates. As mentioned, nominal and real effects (cash flows, liquidity problems versus losses and capital gains), although extremely important in the modern economy and well interpretable in an improved model, go significantly beyond the scope of this article, in which only real effects are discussed.

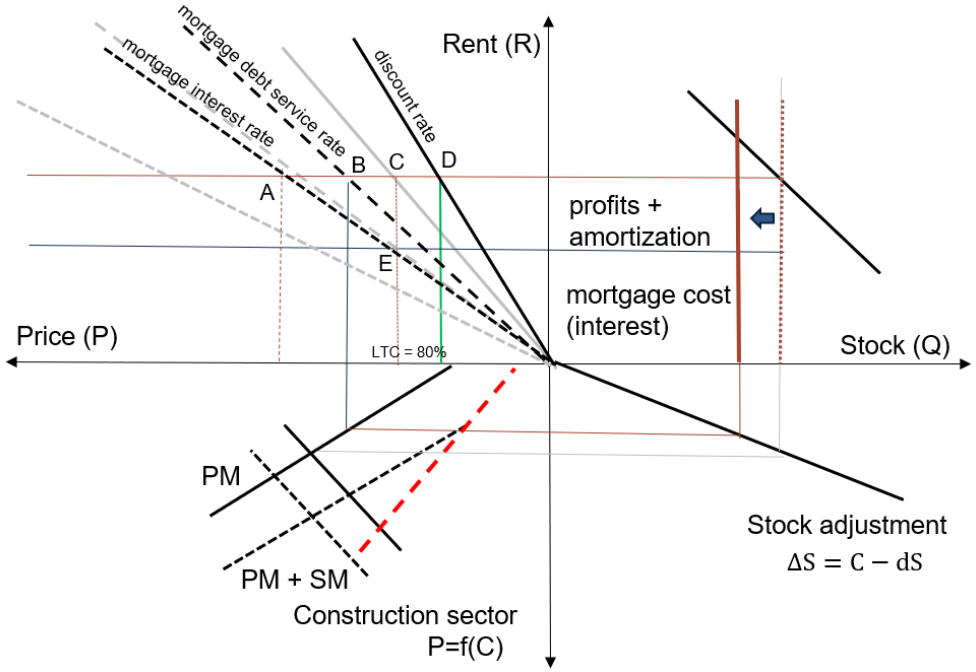
In the classical model, an increase in interest rates causes a decrease in the valuation of new and existing projects. As a result, fewer new projects are implemented (only the cheaper ones, i.e., more effective) and the real estate stock begins to depreciate. This results in a gradual increase in the level of rent after some time, which stimulates valuations and investments to rise to a new point of long-term equilibrium with a lower real estate stock, lower depreciation, lower construction costs, and higher interest rates.

In the modified model, the impact is much more complex and takes place both through the valuation and credit channels and through facility markets, including the secondary market.

In the case of new projects (Figure 3), an increase in interest rates will cause a decrease in the value of the project (higher discount rate) and, consequently, the bank will be willing to issue a lower mortgage. The mortgage availability shifts strongly to the right, the investor will not be able to buy a new building from the developer. On a sectoral scale, this means a decrease in global construction demand and, consequently, a shift in demand down the supply curve (lower supply of projects – lower costs of facilities). If the reduction of the loan and thus the increased interest costs occurred to a similar extent and size (angle) as the increase in the discount rate used for valuation, the volume of profit will decrease, while the rates of return do not have to be significantly adjusted. However, if these values change to a different extent, it will result in greater diversity of the situation. Because of the decline in sectoral supply, the new supply is no longer offers any offset the stock depreciation, resulting in a secular increase in rents. This translates, after some time, into an increase in the value of the project, higher rates of return, and thus an increase in production to the equilibrium level. The model works similarly to the classic DPW model, but it offers extended possibilities for the sectoral situation. In the case of the classic DPW model, this situation practically closes the possibility of the further development of the project, despite the existing practical possibilities of getting out of this situation. The first is the possibility of directing the offer of securities to individual investors with lower expectations regarding the rate of return. The other is that new investment stops and the stock will decline (blue arrow), due to which rents will increase in the long run. We observed a drop in investment transactions on the secondary market between 2022 and 2023, which increased again in 2024, though continuing to remain at a lower level than in 2022. This situation would be difficult to explain by the classical DPW model, with one single curve in Quarter III. But the augmented model explains both, the drop in the demand for new construction and the growth of transactions in the secondary market.

In the case of projects already operating on the market, there is little possibility of adjusting their size or nature, especially the size of the loan taken out. An increase in discount rates with fixed rental income will result in a decrease in the economic value of projects, which will result in a loss of equity and a deterioration of collateral (transition from point). The basic problem is an increase of interest costs on the loan, a decrease

in profits (a loss may occur) and a reduction or even loss of debt servicing. The rate of return on equity calculated in accounting terms will also fall, because economically speaking it may simply "evaporate". The possibilities of rent increases are very limited, as they will result in an increase in vacancy rates in a competitive and declining market. Therefore, the bank will demand additional collateral; it may demand an increase in equity, as this is its risk in the case of debt collection, but its debt collection capabilities are very limited in practice. If the banking sector decides to take over projects in difficulty, it will increase the supply on the property market (the supply curve on the secondary market will move downwards, the new dashed red line) and reduce their prices, contributing to an exacerbation of problems, as supply will increase and credit will decrease (so-called second-round effects), which will cause further loss of value for projects. Possible solutions, apart from changing the purpose of the facility and the plot (high share of the land price), are the commercialization of the own share and the reduction of debt from additional revenues.



Fig, 3. Shock of rising interest rates on the CRE market. New projects. *Source*: own elaboration, based on DiPasquale and Wheaton (1992).

We now show how the model helps to understand the most recent developments in the market. We present the most important factors in Table 1, which covers three scenarios. Case I is the initial case and was presented above. In Case II, we analyze an investor who wants to enter the market under higher construction costs (4098 euro per sqm.) and higher mortgage rates (6.5%). We need to stress that the construction costs are determined by the whole construction sector and not only the volume of new office buildings. At this time, the net rent also increased slightly, i.e. to 21.4 euro per sqm. per month. The mortgage availability of the investor is 21.4*0.8*12/0.065 = 2225 euro per sqm., and the maximal mortgage is 1780 euro per sqm., which is far less than the construction cost. The investor will need to accumulate much more equity to buy or construct a new office building.

Finally, we analyze the investor who bought or constructed the office building just before the interest rates in the eurozone went up (Case III). He now has a higher interest rate payment than in 2022 (3482*0.068/12 = 19.7 euro per sqm. per month) and also a much higher mortgage debt service (3482*0.088/12 = 25.5 euro per sqm. per month). The interest rate payment, and consequently also the payment of the principal, exceed the NOI. The question is whether the bank will grant the investor a mortgage forbearance to stop the payments until the situation improves, that is until interest rates decrease again or rents rise. The sharp increase in interest rates creates pressure on investors and some will be willing to sell their property to pay back the mortgage. Crosignani and Prazad (2024) found that US banks have recently adopted the extend-and-pretend strategy when investors they financed were in trouble. Banks issue a new mortgage with a much larger maturity in such a

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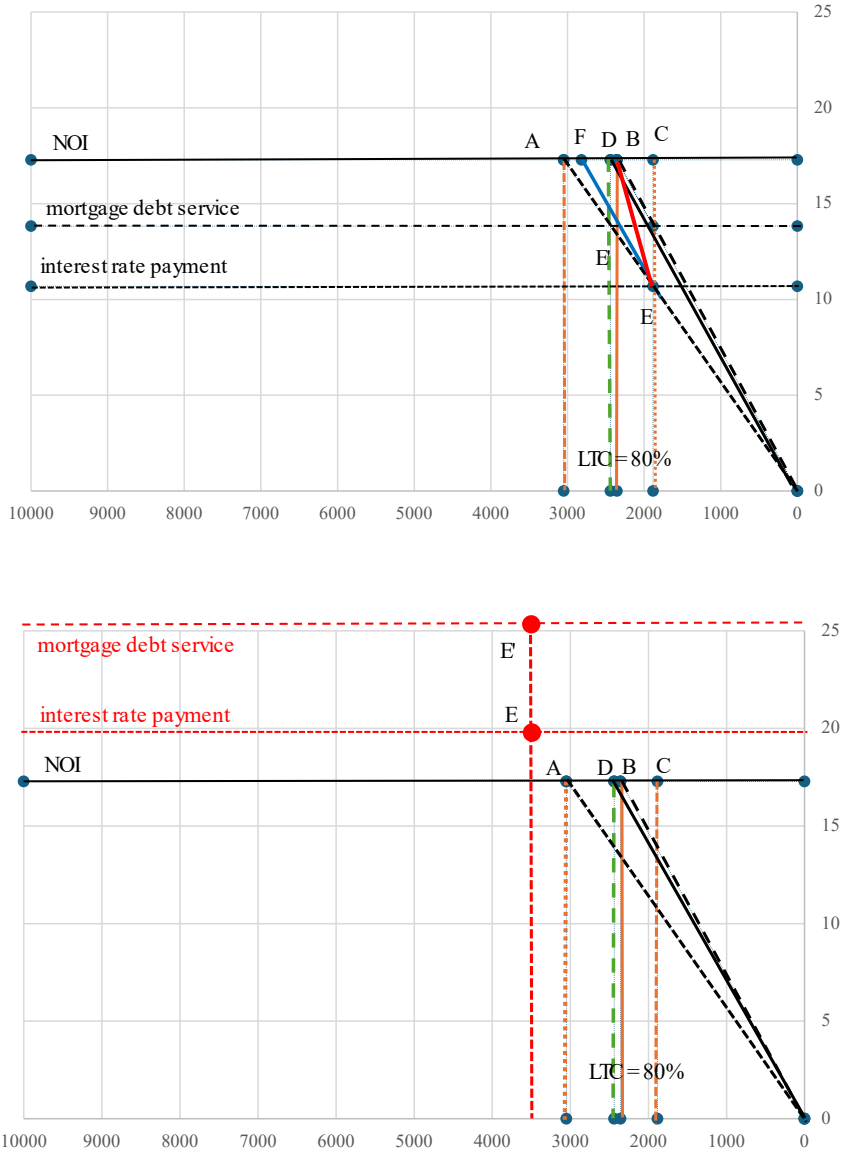
situation, but as the authors state, this creates new problems to the CRE market and financial stability. This is mainly, because less factual new mortgages are issued and capital is allocated less effectively.

Table 1

Main economic factors in the Warsaw office market under three scenarios in euro or in per cent

	Case I	Case II	Case III
maximal mortgage banks would issue	4352	1780	1780
constr.costs per sq m in euro	3619	4098	4098
rent per sq m in euro	20.4	21.6	21.6
discount rate	0.085	0.085	0.085
interest rate	0.025	0.068	0.068
mortgage rate	0.045	0.088	0.088

Source: Own calculations based on data from the NBP (2024, 2025) reports.



Note: The rent in euro per sq meter per month is on the y axis, the value in euro per sq meter on the x axis.

Fig. 4. Zoom into Quadrant II of the modified DPW model, upper panel: the investor wants to enter the market after interest rate increased, lower panel: the investment was carried out before the interest rate increased. *Source*: own elaboration, based on DiPasquale and Wheaton (1992) and data from the NBP (2024, 2025) reports.

5. Conclusions

This extension of the DPW model allows us to understand the factual dynamics in the real estate market. This rather simple model shows us that at least two different interest rates need to be included in a model of the real estate market, which also holds for more technical models. The mortgage rate and the discount rate leads us to two different equilibria, which explains why reasonable investments are not carried out at times. Moreover, the secondary market needs to be considered, because, during a market downturn, some investors decide to exit the market through the secondary market.

The extended model shows to be useful in understanding what happened recently in the Warsaw office market, which has seen a sharp increase in financing costs at the end of 2022 due to the rise of the interest rate in the euro zone and an increase in construction costs, which was caused by the construction boom observed in Poland shortly after the outbreak of the COVID-19 pandemic. While the volume of new construction permits declined in the recent four years, the secondary market, on which investors can buy or sell existing buildings, started to grow in 2024 after a sharp drop of transaction volumes in 2023.

The analysis shows also that, during the artificially low interest rates in the euro zone, banks applied a simple mortgage affordability calculation, but not the more restrictive discounting of the NOI with a proper discount rate which covers the true market risk. However, after the rise of interest rates to levels which can be considered from a historical perspective as normal, the discounting of the NOI with this mortgage rate and the bank discount rate (of 8.5%) lead to similar, prudent valuations.

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