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Inefficient incentives for energy saving in tenancy law and policy options to remedy the landlord-tenant-dilemma

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1 Abstract

The rental building sector is plagued by the so-called landlord-tenant-dilemma, i.e. that landlords have no direct financial benefit from modernizations for energy efficiency if the tenant pays the energy bill while tenants have no incentives to save energy if the landlord pays. The primary landlord-tenant-dilemma occurs due to rent control limiting rent levels in incumbent tenancies and the secondary landlord-tenant-dilemma stems from modernization costs being sunk and thus not reflected in the bargaining over rent levels when a new rental contract is negotiated after a modernization. Tenancy law with an allocation system for energy and modernization costs can help remedying these issues or exacerbate them. This paper develops an analytical model to study how efficiently different allocation systems set modernization and frugality incentives and which ones compare favorably against each other in terms of landlords', tenants', and their combined welfare. I scrutinize a free market, the Swedish inclusive rent system, the German status quo, a slight variation to the German status quo, a consumption based partially inclusive rent system, and a novel demand based partially inclusive rent system. The German status quo actually can theoretically set optimal incentives if it could be setup ideally but it interacts peculiarly with the rest of German tenancy law, impeding optimal design. The demand based partially inclusive rent system could more reliably set efficient incentives but requires a more radical reform of tenancy law.

2 Introduction

The residential building sector causes ca. 11 % of Germany's greenhouse gas emissions with only minor reductions for the last decade (German Environment Agency, 2024), where heat production is the major cause of energy consumption. Not just in light of climate protection but also since Russia's attack on Ukraine and the ensuing price spikes for fossil fuels, reducing this energy consumption has gained more political and economic importance. Germany has one of the largest rental sectors in Europe, with more than half of the building stock being rented out. Therefore, tenancy law with its (in-)ability to set efficient incentives for both modernizations and frugality is an obvious target for economic analysis and eventually knowledge-based recommendations for reform.

The crux of the rental sector are the diverging incentives. When the tenant pays for the energy consumption, as is customary in Germany and many other jurisdictions, the landlord has no direct financial incentive to improve energy efficiency through modernizations. Only the tenant experiences an incentive for frugality. This is known as the landlord-tenant-dilemma, which has been studied a lot in theoretic legal and economic analyses (Ástmarsson et al., 2013; Bird & Hernández, 2012; Charlier, 2015; Henger et al., 2023; Henger et al., 2021; Jaffe & Stavins, 1994; Klinski et al., 2021). It has been shown empirically that landlords indeed typically underinvest in energy efficiency as compared to owner-occupied homes (Charlier, 2015; Gillingham et al., 2012; Murtishaw & Sathaye, 2006; Petrov & Ryan, 2021). The German rental sector, although little data is available (März, 2018), seems to fall in line with this general pattern (Renz & Hacke, 2016; Testorf et al., 2010). This can be summarized to tenancy law setting inefficient incentives for modernizations.

Tenancy law within this paper means a legally prescribed cost allocation system for heating and modernization costs, which are the directly financially measurable components of social costs complemented by the non-financial but very important costs of frugality to the occupant. A cost allocation system could for instance be as simple as “the tenant pays for the consumed energy” and make no statement on the allocation of modernization costs. Such a so-called “cold rent system” relies on the rental market to incentivize landlords to modernize. On the other end of the spectrum lies the “inclusive rent system” where the landlord pays for the consumed energy. This system is for instance employed in Sweden (BBSR, 2016). Between those extremes lie several allocation systems as the one currently in place in Germany or multiple proposed designs for partially inclusive rent systems, where the energy expenditure is somehow shared between landlords and tenants. These allocation systems should first and foremost help setting economically efficient incentives for modernizations and frugality.

Most of the literature analyzing novel allocation systems focus on few ones that are scrutinized in detail (Braungardt et al., 2022; Bürger et al., 2013; Gaßner et al., 2019; Klinski et al., 2009). Furthermore, the analyses usually concentrate on the instant of the tenancy law reform. I expand on this body of the literature by developing a general model that allows for qualitative comparisons of different allocation systems and by assuming that each examined allocation system has already been in place for an indefinite time in order to compare their long-term effects.

This paper examines different allocation systems’ ability to set efficient modernization and frugality incentives for landlords and tenants and the ensuing distributional effects between landlords and tenants.

The analysis is structured as follows: I first develop a general analytic model for frugality and modernization incentives in a rental market to derive socially optimal incentives. I then apply this model to multiple allocation systems to find out how they set incentives for landlords and tenants. In this paper, I analyze seven allocation systems based on their prevalence in the literature: 1) a free market, 2) a market with strict rent control, 3) the Swedish inclusive rent system, 4) the German status quo, 5) a slight variation to the German status quo, 6) a novel consumption based partially inclusive rent system, and 7) a novel demand based partially inclusive rent system. I then compare the effect of the allocation systems on landlords’, tenants’ and their combined welfare. Finally, a conclusion summarizes the results and gives policy recommendations.

3 General model setup and social welfare optimization

Energy expenditure for heating in the residential building sector depends on the technical energy demand of the building and on the occupant's consumption behavior. For a formal analysis of the incentives in the rental sector, I propose the following microeconomic model. Table 2 in the appendix gives an overview of the model's nomenclature.

Assume that any apartment with comfortable heating but without any heating costs generates a welfare surplus between building owner and occupant of $\hat{R} > 0$ which is the difference of what the tenant is at most willing to pay and the minimum rent payment the landlord requires to accept the rental contract. However, this paper focuses on the existing building stock where occupying a building requires heating costs. Without any modernization and with the occupant heating every room to a comfort temperature, the heating costs amount to $P \in (0, C)$, where $C \in (0,1)$ is the building-specific cost factor for energy efficiency modernizations. These heating costs can be reduced by frugal heating decisions of the tenant and modernization by the landlord. Taking $B \in (0,1)$ as the consumption behavior and $M \in (0,1)$ as the degree of modernization, let the actual heating costs be given by $B \cdot (1 - M) \cdot P$. Obviously, frugality comes at a cost. Let $\frac{(1-B)^2}{2}$ be the occupant's frugality costs. Similarly, let $\frac{C \cdot M^2}{2}$ be the modernization costs. Assume that the energy required of heating the apartment to comfort level without any frugality can be technically calculated at least for the representative occupant and is recorded in a demand based energy performance certificate. Absent any externalities, the contribution of renting out an apartment, and heating it, to social welfare is then given by:

$$W \equiv \hat{R} - (1 - M) \cdot P \cdot B - \frac{(1 - B)^2}{2} - \frac{C \cdot M^2}{2} \qquad (1)$$

Note that all measures of costs and wellbeing are normalized to the discomfort the occupant experiences from deviating from the comfort temperature. Therefore, C and especially P can also somewhat be interpreted as a measure of the occupant's financial wealth: less affluent households are more financially pressed to reduce energy consumption in order to save on energy costs. Therefore, their relative frugality costs compared to energy costs are lower, or in terms of the model, P and thus also C tend to be larger.

Both variables are intertwined and together represent the building's energy efficiency. High values of C indicate larger costs associated with an energy retrofit, e.g. for buildings with a challenging architecture or which are under a preservation order. Larger values of P correspond to buildings which achieve a comfortable living temperature only under considerable costs, e.g. poorly insulated buildings or buildings which use an expensive fuel.

The simple quadratic cost function for modernizations and frugality captures the standard observation of increasing marginal costs of energy cost reductions while still allowing for relative algebraic ease in the analysis. Note that I focus my model on the final energy required for heating the building because I am interested in the interaction of the owner's modernization decision and the occupant's consumption behavior for heating. I therefore limit the modernization effect to be at most a reduction of the energy demand to zero by constraining P to C. While a net positive final energy demand for a retrofitted building as a whole is plausible, e.g. by a combination of insulation, a heat pump, and PV-electricity production, the social planner would still optimize heating behavior against the electricity price since more frugality means more power that could be sold off to the grid.

Considering the external costs of climate change, this assumption holds for most of the existing building stock. However, without proper internalization of the externality, some buildings should be modernized but this modernization is too costly to yield sufficient energy and frugality cost savings due to insufficient energy prices. When proper internalization is somehow not a feasible option, but the legislator still wishes for modernizations to be incentivized via tenancy law, the incumbent tenant must obviously lose from the modernization. That is because the landlord will only modernize if she[1] benefits from it, leaving the tenant paying for the modernization's net costs as well as for the landlord's profits. This distributive problem cannot be solved via tenancy law and only highlights the necessity of proper internalization of climate change damages. To concentrate on the incentive and distributive effects of the allocation systems, the model therefore abstracts from any externalities - either because there are none or because they are perfectly internalized.

Social welfare W is maximized when $M^{\star}_{SP} \equiv \frac{P\cdot(1-P)}{C-P^2}$ and $B^{\star}_{SP} \equiv 1 - P \cdot (1 - M^{\star}_{SP}) = \frac{C\cdot(1-P)}{C-P^2}$. Note that $\{M^{\star}_{SP}, B^{\star}_{SP}\} \in (0,1)^2$ for $0 < P < C < 1$.

4 The allocation systems

I now turn to the rental market where the building owner – the landlord – and the building's occupant – the tenant – are different people who negotiate over the rent levels. I develop a general bargaining model for rent payments in the light of energy, frugality and modernization costs which is then adapted to each allocation system.

4.1 The general bargaining model for rent levels

The general model consists of three separated Nash bargaining games between landlord and prospective tenant depending on the allocation system. Since no two apartments on the market for rental are exactly alike, even if only separated by minute details such as the location within a building influencing solar irradiation, I assume that a landlord willing to rent out the apartment and a prospective tenant negotiate over the rent payment. This negotiation may not be explicit but mediated through the asking price a landlord lists based on her experience.

The first bargaining game is initiated when nature pairs the landlord offering an apartment with given energy efficiency with a prospective tenant. Both parties form expectations on the average energy consumption costs $P \cdot \widetilde{B_\sigma^{pre}}$ with privately optimal consumption behavior based on the energy performance certificate and the ensuing expected frugality costs of $\frac{\left(1-\widetilde{B_\sigma^{pre}}\right)^2}{2}$.

Here and in what follows, the superscripts pre and $post$ indicate the modernization status before and after the modernization and the subscript $\sigma \in \{SP, FM, RC, IR, MS, RIMA, CB, DB\}$ denotes the allocation system. Furthermore, the tilde $\sim$ shows that the associated variable equals the agents' expectation. Moreover, the dummy variables[2] $\alpha_{RC,\sigma}, \dots, \alpha_{DB,\sigma} \in \{0,1\}$ characterize the legal design of the allocation systems as shown in Table 1. Note that S, A, N, and D are variables specific to their respective allocation systems and will be defined in the appropriate sections to come.

Table 1: Model specification for each allocation system

σ	$\alpha_{RC,\sigma}$	$\alpha_{IR,\sigma}$	$\alpha_{MS,\sigma}$	$\alpha_{RIMA,\sigma}$	$\alpha_{CB,\sigma}$	$\alpha_{DB,\sigma}$
FM	0	0	0	0	0	0
RC	1	0	0	0	0	0
IR	1	1	0	0	0	0
MS	1	0	1	0	0	0

[1] To avoid ambiguity when using pronouns to refer to the agents, I assign female pronouns to the landlord and male pronouns to the tenant.

[2] Theoretically, mixed allocation systems where $\alpha_{RC,\sigma}, \dots, \alpha_{DB,\sigma}$ assume values between zero and unity are possible. However, they are politically and legally implausible and thus not studied further.

RIMA	1	0	0	1	0	0
CB	1	1	0	0	1	0
DB	1	0	0	0	0	1

The two parties agree that these energy consumption costs diminish the value $\hat{R}$ the apartment provides. Whatever welfare surplus is left is the basis for the agents' bargaining game, where they eventually agree on a rent level R_σ^{pre} that distributes the welfare surplus according to the landlord's bargaining power $\beta \in (0,1)$.

$$R_\sigma^{pre} \equiv \underbrace{\beta \cdot \left(\hat{R} - P \cdot \widetilde{B_\sigma^{pre}} - \frac{\left(1 - \widetilde{B_\sigma^{pre}}\right)^2}{2} \right)}_{\substack{landlord's\ share\ in \\ apartment's\ value\ w/\ expected \\ energy\ and\ frugality\ costs}} + \underbrace{\alpha_{IR,\sigma} \cdot P \cdot B_\sigma^{pre}}_{\substack{landlord's\ expected\ energy \\ costs\ in\ inclusive \\ rent\ system}} + \underbrace{\alpha_{DB,\sigma} \cdot P \cdot D}_{\substack{reimbursement\ in \\ demand\ based\ partial \\ inclusive\ rent\ system}} \qquad (2)$$

This conceptualization of bargaining power and discounts for energy costs can offer an explanation to the finding of Kholodilin et al. (2017) and Sieger and Weber (2023) that reductions in monthly energy costs by 1.00 € only yield roughly 0.25 € in additional rents: when comparing a better insulated apartment to one with poor energy efficiency, the tenant thus benefits by 75 % of the energy cost savings. This implies that on the German market for new tenancies, bargaining power with regard to energy efficiency seems to lie rather with the tenant.

Once the rent level R_σ^{pre} is agreed upon, the tenant moves in and chooses a consumption behavior B_σ^{pre} based on the incentive structure set by the allocation system. Crucially, the rent level cannot be changed based on the tenant's actually recorded behavior. Once the tenant chose his behavior, both agents' payoffs materialize as rent and energy consumption costs have to be paid. The landlord's profits are given by L_σ^{pre} and the tenant's payoffs are T_σ^{pre}.

$$L_\sigma^{pre} \equiv \underbrace{R_\sigma^{pre}}_{\substack{rent \\ pre \\ modernization}} - \underbrace{\alpha_{IR,\sigma} \cdot P \cdot B_\sigma^{pre}}_{\substack{landlord's\ energy \\ costs\ in\ inclusive \\ rent\ system}} - \underbrace{\alpha_{DB,\sigma} \cdot P \cdot D}_{\substack{reimbursement\ in \\ demand\ based\ partial \\ inclusive\ rent\ system}} \qquad (3)$$

$$\begin{aligned} T_\sigma^{pre} \equiv & \underbrace{\left(\hat{R} - P \cdot B_\sigma^{pre} - \frac{\left(1 - B_\sigma^{pre}\right)^2}{2} \right)}_{\substack{apartment's\ value\ w/\ energy \\ and\ frugality\ costs}} - \underbrace{R_\sigma^{pre}}_{\substack{rent \\ pre \\ modernization}} + \underbrace{\alpha_{IR,\sigma} \cdot P \cdot B_\sigma^{pre}}_{\substack{landlord's\ energy \\ costs\ in\ inclusive \\ rent\ system}} \\ & + \underbrace{\alpha_{DB,\sigma} \cdot P \cdot D}_{\substack{reimbursement\ in \\ demand\ based\ partial \\ inclusive\ rent\ system}} + \underbrace{\frac{\alpha_{CB,\sigma}}{N} \cdot P \cdot \left(B_\sigma^{pre} - \widetilde{B_\sigma^{pre}} \right)}_{\substack{neighborhood\ incentive \\ in\ consumption\ based\ partial \\ inclusive\ rent\ system}} \end{aligned} \qquad (4)$$

At some point in time, nature randomly prompts the landlord to consider and choose a modernization. That occasion may be marked e.g. by a change in ownership or by necessary maintenance that eases the consideration of far reaching retrofit activity. After the modernization, both parties again form expectations on the now smaller energy and frugality costs $P \cdot \widetilde{B_\sigma^{post}}$ and $\frac{\left(1 - \widetilde{B_\sigma^{post}}\right)^2}{2}$. They then alter their rental agreement based on the allocation system. In most of the studied allocation systems, they do not renegotiate the rent level but rather change or maintain the rent payments in a legally prescribed manner. This is where the primary landlord-tenant-dilemma becomes visible: when rent control limits rent increases in ongoing tenancies but the tenant pays for the energy bill, he gains the energy and frugality cost savings from the modernization but the landlords has to bear the investment costs. If they negotiate a new rent level, they agree on a payment of R_σ^{post}.

$$R_\sigma^{post} \equiv \beta \cdot \underbrace{\left(\hat{R} - (1 - M_\sigma) \cdot P \cdot \widetilde{B_\sigma^{post}} - \frac{\left(1 - \widetilde{B_\sigma^{post}}\right)^2}{2}\right)}_{\substack{landlord's\ share\ in\\ apartment's\ value\ w/\ expected\\ energy\ and\ frugality\ costs}} + \underbrace{\alpha_{IR,\sigma} \cdot (1 - M_\sigma) \cdot P \cdot \widetilde{B_\sigma^{post}}}_{\substack{landlord's\ expected\ energy\\ costs\ in\ inclusive\\ rent\ system}} \tag{5}$$

$$+ \underbrace{\alpha_{DB,\sigma} \cdot (1 - M_\sigma) \cdot P \cdot D}_{\substack{reimbursement\ in\\ demand\ based\ partial\\ inclusive\ rent\ system}} + \underbrace{\alpha_{RIMA,\sigma} \cdot A \cdot \frac{C \cdot {M_\sigma}^2}{2}}_{\substack{modernization\\ apportionment}}$$

The tenant then proceeds to choose a consumption behavior B_σ^{post} and the incumbent tenant's pay-offs IT_σ^{post}materialize where the weight $\mu \in (0,1)$ reflects the duration of the tenancy after the modernization.

$$IT_\sigma^{post} \equiv \mu \cdot \left(\underbrace{\left(\hat{R} - (1 - M_\sigma) \cdot P \cdot B_\sigma^{post} - \frac{\left(1 - B_\sigma^{post}\right)^2}{2}\right)}_{\substack{apartment's\ value\ w/\ energy\\ and\ frugality\ costs}} - \underbrace{\alpha_{Rc,\sigma} \cdot R_\sigma^{pre}}_{\substack{pre\ modernization\\ rent\ w/\ rent\ control}} \right.$$

$$- \underbrace{\left(1 - \alpha_{4,\sigma}\right) \cdot R_\sigma^{post}}_{\substack{post\ modernization\\ rent\ w/o\ rent\ control}} + \underbrace{\alpha_{IR,\sigma} \cdot (1 - M_\sigma) \cdot P \cdot B_\sigma^{post}}_{\substack{landlord's\ energy\\ costs\ in\ inclusive\\ rent\ system}} \tag{6}$$

$$+ \underbrace{\alpha_{DB,\sigma} \cdot (1 - M_\sigma) \cdot P \cdot D}_{\substack{reimbursement\ in\\ demand\ based\ partial\\ inclusive\ rent\ system}} + \underbrace{\frac{\alpha_{CB,\sigma}}{N} \cdot (1 - M_\sigma) \cdot P \cdot \left(B_\sigma^{post} - \widetilde{B_\sigma^{post}}\right)}_{\substack{neighborhood\ incentive\\ in\ consumption\ based\ partial\\ inclusive\ rent\ system}}$$

$$\left. - \underbrace{\left(\alpha_{MS,\sigma} \cdot S + \alpha_{RIMA,\sigma} \cdot A\right) \cdot \frac{C \cdot {M_\sigma}^2}{2}}_{\substack{legally\ prescribed\ rent\ increases\\ in\ modernization\ surcharge\ or\\ rent-indepentend\ modernization\ apportionment}} \right)$$

At a third stage, nature terminates the incumbent tenancy, for instance because the tenant moves to another city. The landlord again advertises the apartment and finds a new prospective tenant with whom the first bargaining game is repeated with now decreased energy and frugality costs. The bargaining results in a rent level of R_σ^{post}. The future tenant moves in and chooses the same consumption behavior B_σ^{post} as the incumbent tenant and receives payoffs of FT_σ^{post}. Note that the incumbent tenant and the future tenant can be summed up to a combined tenant T_σ^{post} to compare how each allocation system generally treats tenants compared to landlords: $T_\sigma^{post} \equiv IT_\sigma^{post} + FT_\sigma^{post}$.

$$FT_\sigma^{post} \equiv (1-\mu) \cdot \left(\underbrace{\left(\hat{R} - (1-M_\sigma) \cdot P \cdot B_\sigma^{post} - \frac{\left(1-B_\sigma^{post}\right)^2}{2}\right)}_{apartment's\ value\ w/\ energy\ and\ frugality\ costs} - \underbrace{R_\sigma^{post}}_{post\ modernization\ rent} + \underbrace{\alpha_{IR,\sigma} \cdot (1-M_\sigma) \cdot P \cdot B_\sigma^{post}}_{landlord's\ energy\ costs\ in\ inclusive\ rent\ system} + \underbrace{\alpha_{DB,\sigma} \cdot (1-M_\sigma) \cdot P \cdot D}_{reimbursement\ in\ demand\ based\ partial\ inclusive\ rent\ system} + \underbrace{\frac{\alpha_{CB,\sigma}}{N} \cdot (1-M_\sigma) \cdot P \cdot \left(B_\sigma^{post} - \widetilde{B_\sigma^{post}}\right)}_{neighborhood\ incentive\ in\ consumption\ based\ partial\ inclusive\ rent\ system} - \underbrace{\alpha_{RIMA,\sigma} \cdot A \cdot \frac{C \cdot {M_\sigma}^2}{2}}_{modernization\ apportionment} \right) \tag{7}$$

The landlord chooses the extent of the modernization based on the expected payoffs from the incumbent tenant after the modernization and from the future tenant. Note that the modernization costs $\frac{C \cdot {M_\sigma}^2}{2}$ are sunk costs (Grout, 1984) and do not factor in the rent negotiations in the second and third bargaining game as there is no plausible possibility for the incumbent tenant nor by far any way for the future tenant to negotiate an a priori contract with the landlord over the modernization and the consumption behavior. This marks the secondary landlord-tenant-dilemma, where the landlord cannot enter the paid modernization costs into the bargaining game, therefore only receiving a rent premium for the energy and frugality cost savings but not the modernization costs. The landlord's payoffs after the modernization are given by L_σ^{post}.

$$L_\sigma^{post} \equiv \underbrace{\alpha_{RC,\sigma} \cdot \mu \cdot R_\sigma^{pre}}_{incumbent\ tenant's\ rent\ w/\ rent\ control} + \underbrace{\left(1-\alpha_{RC,\sigma} \cdot \mu\right) \cdot R_\sigma^{post}}_{future\ tenant's\ rent\ post\ modernization\ (both\ tenants'\ w/o\ rent\ control)} - \underbrace{\frac{C \cdot {M_\sigma}^2}{2}}_{modernization\ costs} - \underbrace{\alpha_{IR,\sigma} \cdot (1-M_\sigma) \cdot P \cdot B_\sigma^{post}}_{landlord's\ energy\ costs\ in\ inclusive\ rent\ system} - \underbrace{\alpha_{DB,\sigma} \cdot (1-M_\sigma) \cdot P \cdot D}_{reimbursement\ in\ demand\ based\ partial\ inclusive\ rent\ system} + \underbrace{\left(\alpha_{MS,\sigma} \cdot \mu \cdot S + \alpha_{RIMA,\sigma} \cdot A\right) \cdot \frac{C \cdot {M_\sigma}^2}{2}}_{legally\ prescribed\ rent\ increases\ in\ modernization\ surcharge\ or\ rent-independentend\ modernization\ apportionment} \tag{8}$$

Figure 1 gives an overview of the sequencing in the bargaining game.

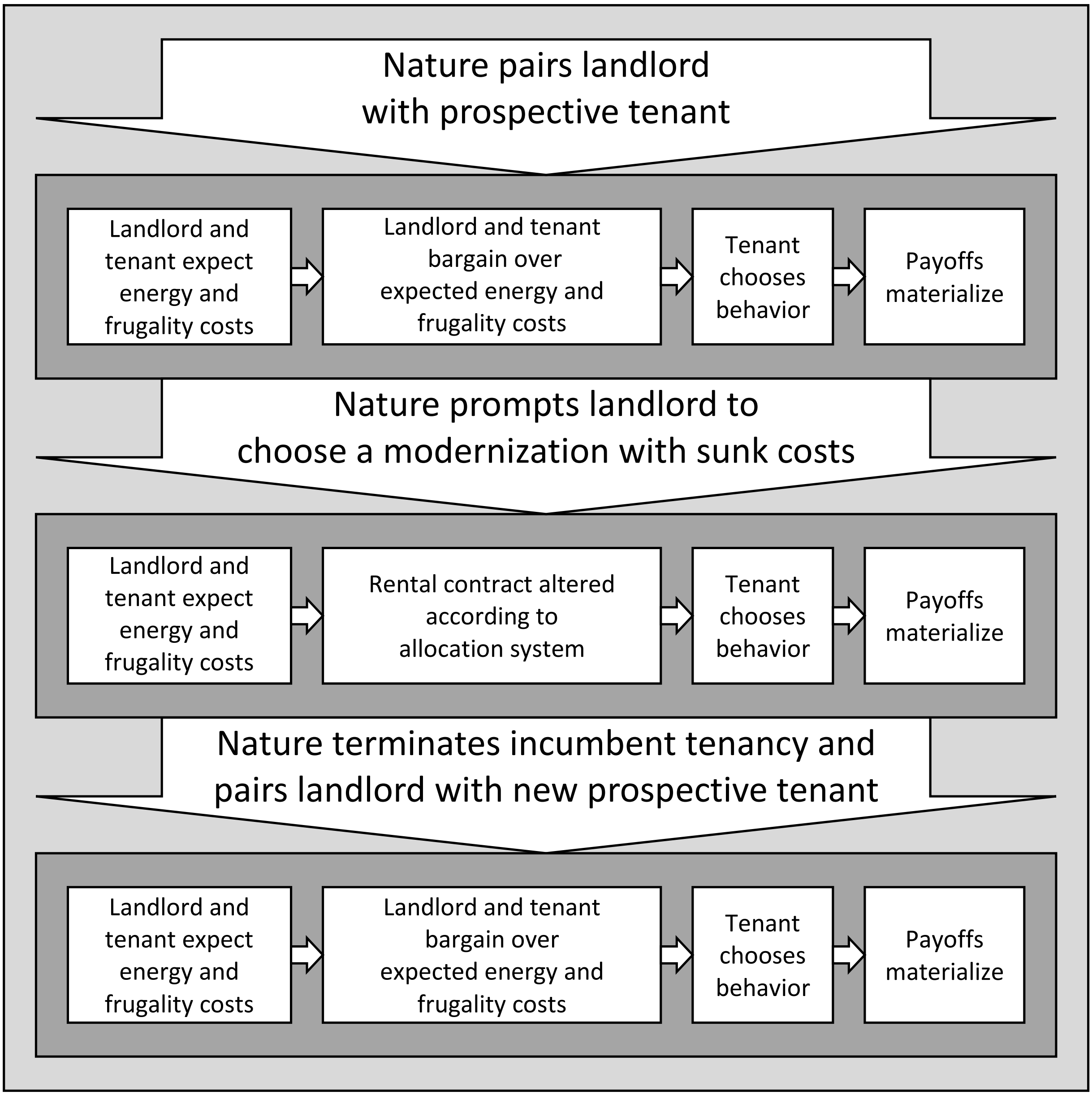


Figure 1: Sequencing of the bargaining game between landlord and tenant.

4.2 Free cold rent market

I first focus on a free cold rent market, i.e. the tenant pays the utility bill and both landlord and tenant have perfect information on the energy performance of each building and the respective costs for modernizations and frugality. Furthermore, I assume total enforcement of contracts and tenancy law throughout this paper. Without any further payments prescribed by the legislator, the allocation system is fully described in Table 1. Note that For the free market, $\{\alpha_{RC,FM}, \dots, \alpha_{DB,FM}\} = \{0, \dots, 0\}$.

Since in the modelled free market the tenant pays for the energy costs and receives no transfers from the landlord, the payoffs reduce to

$$L_{FM}^{pre} = R_{FM}^{pre} \text{ and } T_{FM}^{pre} = \hat{R} - R_{FM}^{pre} - P \cdot B_{FM}^{pre} - \frac{\left(1-B_{FM}^{pre}\right)^2}{2}.$$

Given these payoffs, both parties expect the tenant to choose $B_{FM}^{pre} = \widetilde{B_{FM}^{pre}} \equiv 1 - P$. Since the tenant bears the entire marginal energy costs, he behaves as frugally as the social planner would dictate given no modernization.

After the modernization, the benefits of the decreased energy and frugality costs are shared between landlord and tenant according to their bargaining power, but the modernization costs remain as sunk costs with the landlord. This implies that the landlord has an insufficient modernization incentive and thus chooses a modernization of $M_{FM}^{\star} \equiv \frac{P\cdot(1-P)}{\frac{1}{\beta}\cdot C-P^2} < M_{SP}^{\star}$. As a response, the tenant lives more frugally than what would be necessary if the modernization incentive was efficient: $B_{FM}^{post^{\star}} \equiv 1 - P \cdot (1-M_{FM}^{\star}) = \frac{\frac{1}{\beta}\cdot C\cdot(1-P)}{\frac{1}{\beta}\cdot C-P^2} < B_{SP}^{\star}$. The sequencing of the bargaining game causing the modernization costs to be sunk leads to a suboptimal outcome even when assuming most favorable market conditions.

Figure 2 shows the distribution of costs and benefits of the apartment before and after the modernization. It is parametrized to $\hat{R} = 0.3, P = 0.21, C = 0.7, \beta = 0.25, \mu = 0.7$, which is the same parametrization as for all similar plots to follow. While the modernization nominally increases the rent level, both agents benefit from the difference of modernization costs to savings in energy costs and frugality costs. However, since the landlord's bargaining power is chosen to be small at $\beta = 0.25$ in accordance with the findings of Kholodilin et al. (2017) and Sieger and Weber (2023), the secondary landlord-tenant-dilemma weighs heavy and bars the landlord from meaningfully benefitting from the modernization. She therefore chooses only a miniscule modernization that barely reflects in the diagram. Section 5 studies the effects of variance in the market variables β and μ.

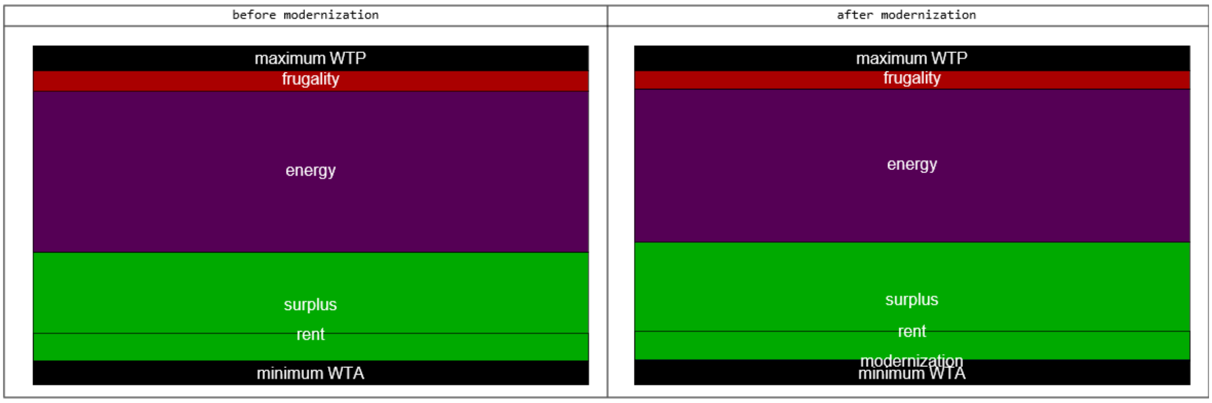


Figure 2: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the free market before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level.

Overall, even the idealized free market fails to yield the socially optimal outcome due to insufficient modernization incentives and thus excessive frugality. This shows that some policy intervention is necessary to rectify the market imperfection, as most European jurisdictions attempt (BBSR, 2016).

4.3 Free market with strict rent control for ongoing tenancies

I now introduce a model of strict rent control, i.e. some form of tenancy law that inhibits unilateral rent increases dictated by the landlord. While I am unaware of any jurisdictions with such a strict rent control, Germany, for instance, can be argued to employ a somewhat similar system where the rent levels in ongoing tenures may only be increased unilaterally and limited up to the reference rent customary in the locality, i.e. the rent level that has been agreed upon over the last six years for new tenures for a similar apartment. The German regulation enables extraordinary rent increases after a modernization, which I will model and analyze in the next section, but for now I focus on the effects of strict rent control on ongoing tenures and a free and fully informed market for new rental agreements to illustrate the primary landlord-tenant-dilemma.

The strict rent control introduces the necessity to distinguish between incumbent tenancies and newly formed rental agreements after a modernization as outlined in the general model description. Before the modernization and for those newly formed contracts with future tenants, the rent control market behaves just as the free market. However, for the share $\mu \in (0,1)$ of the modernization's (discounted) project lifetime, the landlord may not increase the rent due to rent control. This share may be determined by the remaining duration of the incumbent tenant's contract or by some policy. In Germany, for instance, the rent in ongoing tenancies may usually not be unilaterally increased unless it is lower than the reference rent customary in the locality (Sec. 559 German Civil Code[3]) which in theory is supposed to represent the current market valuation of the apartment. In this case, μ corresponds to the time until the reference rent has sufficiently increased to warrant adjusting the rent level. The landlord may thus not expect additional rent revenue for some share of the project lifetime, decreasing the incentive to invest.

Within the model, the rent control policy is captured by $\alpha_{RC,RC} = 1$. Here and forthcoming, all of the not explicitly mentioned dummy variables $\alpha_{RC,\sigma}, \dots, \alpha_{DB,\sigma}$ equal 0. Before the modernization, nothing changes compared to the free market. However, due to the further decreased incentive to invest, the landlord chooses a smaller modernization extent to which both the incumbent and the future tenant react with greater frugality: $M^{\star}_{RC} \equiv \frac{P\cdot(1-P)}{\frac{1}{\beta\cdot(1-\mu)}\cdot C - P^2} < M^{\star}_{FM} < M^{\star}_{SP}$ and $B^{post^{\star}}_{RC} \equiv 1 - P \cdot (1 - M^{\star}_{RC}) = \frac{\frac{1}{\beta\cdot(1-\mu)}\cdot C\cdot(1-P)}{\frac{1}{\beta\cdot(1-\mu)}\cdot C - P^2} < B^{\star}_{FM} < B^{\star}_{SP}$. Figure 3 shows the distribution of costs and benefits of the apartment before and after the modernization. As can be seen, the secondary landlord-tenant-dilemma due to the low bargaining power of the landlord still impedes meaningful modernizations. This issue is amplified by the large weight of incumbent tenants, introducing the primary landlord-tenant-dilemma and thus causing the landlord to almost not invest at all.

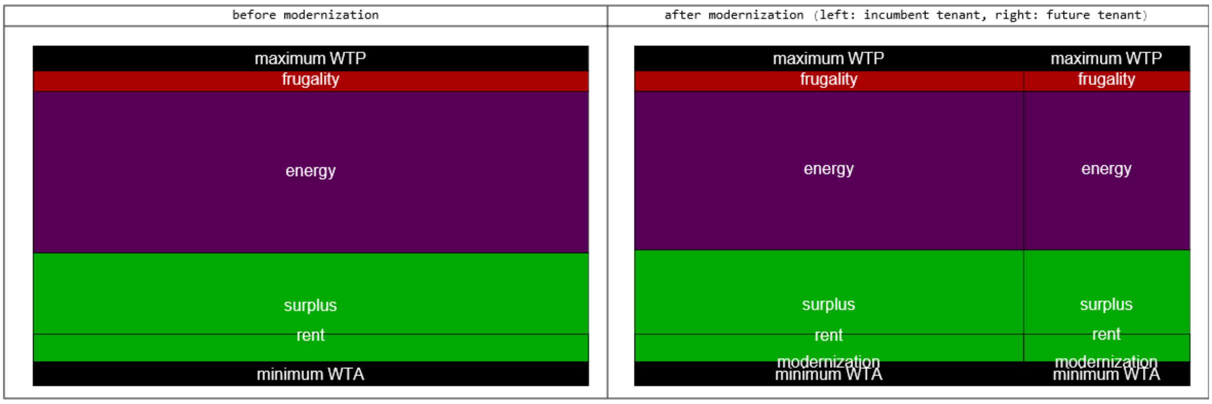


Figure 3: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the rent control market before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level.

As with the fully idealized efficient market, the very strict rent control without any legal incentive to modernize within ongoing tenancies is implausible as a realistic policy option and will thus not be examined further. However, it is equally implausible for jurisdictions with existing rent control measures in order to protect incumbent tenants from exploitative rent levels to fully drop tenant protection as a policy goal. Therefore, the policy options discussed in the remainder of this analysis preserve the

[3] Bürgerliches Gesetzbuch – BGB.

differentiation between a highly regulated market for incumbent tenants and a less regulated market for future tenants while aiming to set as efficient incentives as possible.

4.4 Inclusive rent system

Another radical allocation system is the so called inclusive rent system as it is customary in Sweden (Thomaßen et al., 2020). Here, landlords and tenants agree on a rental payment that includes the (expected) energy consumption costs. The tenant then faces no more variable energy costs, so he has no incentive for frugality. On the other hand, the landlord reaps the entire benefits from modernizations. In the model, this is captured by $\alpha_{IR,IR} = 1$ and $\alpha_{RC,IR} = 1$.

Having the landlord pay for the consumed energy bill without any metering of the tenant's consumption behavior influences rent levels before the modernization in two ways. First, rent should increase by the expected energy consumption costs. Second, the tenant has no more incentive to behave frugally, increasing the energy costs by more than what the frugality costs would be if the tenant behaved energy consciously. This decreases the welfare surplus generated by the apartment. This cannot be mitigated by the tenant promising to behave frugally for both parties' benefit as this promise is not very credible if there is no metering of the tenant's behavior and thus no financial incentive to keep the promise. Modernizing in the inclusive rent system has a larger absolute impact on energy costs as there is no rebound effect from less frugal behavior since tenants always heat their apartment up to comfort temperature. The landlord's modernization incentives are given by the incumbent tenant causing lower energy costs. Due to the modernization costs being sunk, the landlord has to hand over some of these energy cost savings to future tenants according to their respective bargaining powers. This all leads to an optimal modernization of $M^{\star}_{IR} \equiv \frac{P}{C} > M^{\star}_{SP} > M^{\star}_{FM}$ and $B^{post^\star}_{IR} \equiv 1 > B^{\star}_{SP} > B^{\star}_{FM}$. Relieving the tenant from any incentive to frugality obviously causes excessive consumption compared to the social optimum and to a likewise excessive modernization by the landlord as can be seen in Figure 4. This figure shows very well the effect of the secondary landlord-tenant-dilemma on the landlord, whose modernization costs are sunk and thus fully remain with her.

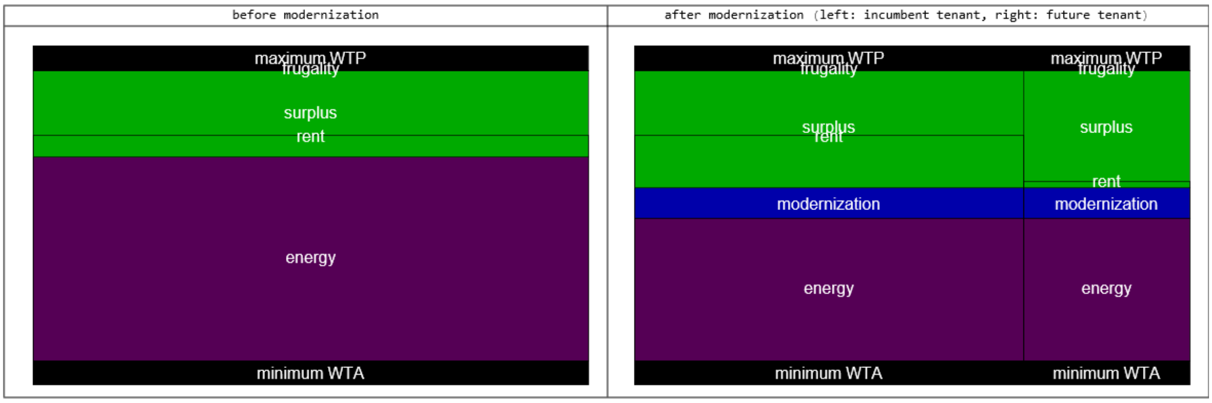


Figure 4: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the inclusive rent rent market before and after a modernization. The black bars are the boundaries for negotiation, the purple bar is the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level.

As with the strict rent control market, the pure inclusive rent system is excluded from further analysis. While it indeed ensures that landlords have a large incentive to modernize, it completely relieves tenants from responsibility for the energy costs, thereby introducing new inefficiencies. Furthermore, newly introducing an inclusive rent system within the EU is ruled out by the EU Energy Efficiency Directive (EED) which posits that energy consumption must (at least in parts) be paid for by the consumer who has direct control over whether or not to turn on the heating. This actual energy consumption must be metered and billed accordingly. Sweden may only continue with the inclusive rent system as it is argued that installing new metering and billing infrastructure would cost more than the additional energy savings (Thomaßen et al., 2020). However, it is nonetheless included in this section as the consumption based partially inclusive rent system outlined below borrows from the inclusive rent system and even devolves into it when buildings only include one housing unit.

4.5 German modernization surcharge

I now turn to the system that Germany currently employs to incentivize modernizations within the rental housing sector. Without any modernizations, when first agreeing on a rental contract, there are only few restrictions, so simply assuming a well-informed market is plausible. However, once a tenancy agreement has been reached, there is rent control in place which limits rent increases as outlined above, with the exception that a share of the modernization cost may be placed on the incumbent tenant. This rent premium is called the modernization surcharge (MS). German tenancy law focuses on the modernization costs because among actual energy costs which also depend on the tenants' behavior, they are most tangible and easy to unilaterally implement in the rental contract. Within the model, the German surcharge is characterized by $\alpha_{RC,MS} = 1$ and $\alpha_{MS,MS} = 1$ with the former turning on rent control and the latter implementing the modernization surcharge. The landlord may unilaterally increase the rent level for the incumbent tenant by $\cdot \frac{S \cdot C \cdot {M_{MS}}^2}{2}$, that is by some proportion $S \in (0, \infty)$ of her modernization costs.

In German legislation, the modernization surcharge is limited to increasing the annual rent by 8 % of the modernization costs, but the monthly rent by not more than EUR 3 per square meter, or EUR 2 for apartments with an initial rent of less than EUR 7 per square meter (Sec. 558 BGB). However, as the modernization surcharge interacts with the reference rent customary in the locality, it is uncertain for how long the landlord gains additional rent revenue. Furthermore, the additional revenue decreases over time as the rent with modernization surcharge may not be increased any further but the reference rent, which the landlord could demand without the modernization surcharge, tends to increase over time. The German system thus cannot explicitly set a value of S that is applied to all rental contracts, but it rather deploys a set of rules which implicitly result in a certain value of S that is individual to each rental contract with its specific market conditions. Generally, the resulting value of S tends to be larger when tenant turnover in the market is lower and thus the landlord has more time to benefit from the modernization surcharge rent increase.

In my model, the possibility for the landlord to levy some of the modernization costs onto the incumbent tenant obviously increases the modernization incentive compared to the strict rent control system. In fact, depending on the value of S, the modernization incentive may even be excessive compared to the socially optimal modernization; $M^{\star}_{MS} \equiv \frac{P \cdot (1-P)}{\frac{(1-\mu \cdot S)}{\beta \cdot (1-\mu)} \cdot C - P^2} \lesseqgtr M^{\star}_{SP}$. The tenants, on the other hand, always pay for the actual energy consumption costs. They therefore react optimally to the chosen modernization. $B^{post\star}_{MS} \equiv 1 - P \cdot (1 - M^{\star}_{MS}) = \frac{\frac{(1-\mu \cdot S)}{\beta \cdot (1-\mu)} \cdot C \cdot (1-P)}{\frac{(1-\mu \cdot S)}{\beta \cdot (1-\mu)} \cdot C - P^2} \lesseqgtr B^{\star}_{SP}$. As can be seen, both landlord and tenant behave socially optimal when $S = S^{\star} \equiv \frac{1-\beta \cdot (1-\mu)}{\mu} > 1$, that is when the incumbent tenant pays more than the annuity costs of the modernization in order to balance the sunk costs problem in the free market for new tenancies. The incumbent tenant should bear the full share of modernization costs for as long as he benefits from rent control, as he also reaps the full benefits of reduced energy and frugality costs, and, on top, the share of the modernization costs that the future tenant would bear according to bargaining power if there was a complete contract and no problem of sunk costs. Figure 5 shows the distribution of costs and benefits where S is parametrized to $S = S^{\star} \approx 1.32$.

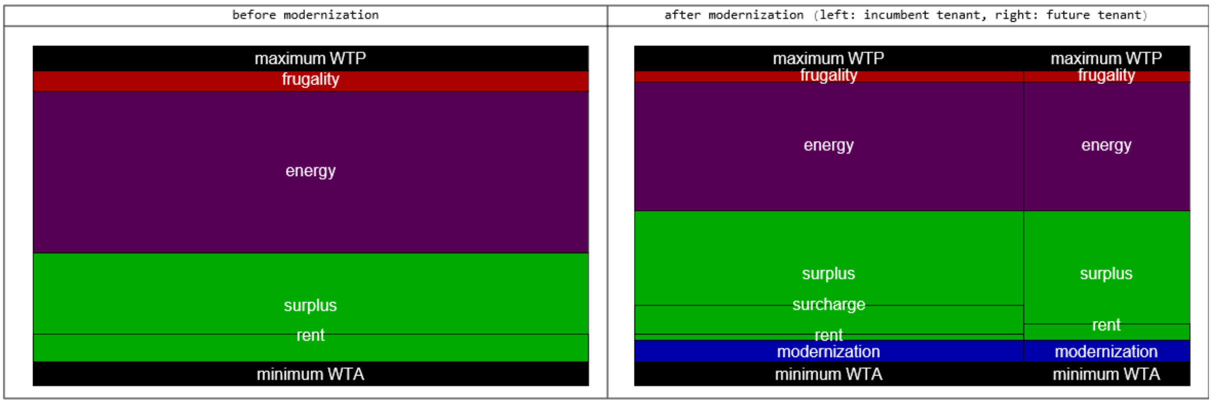


Figure 5: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the modernization surcharge system before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level, with a second horizontal bar in the second panel showing the modernization surcharge.

The results of the model analysis clearly show that the German modernization surcharge as modelled induces the socially optimal outcome when setup properly. This result seemingly counters the notion laid out in the introduction that Germany currently displays sub-optimal modernization behavior which can be explained by the details of the law as it is. The current implementation of the modernization surcharge has peculiar temporal effects on both landlords and tenants. After a modernization, the rent payments may be unilaterally increased in proportion to the modernization costs. Afterwards, the monthly rent may not be increased any further until the so called reference rent customary in the locality has reached the rent level with the modernization surcharge. The reference rent is supposed to mirror the market value of the apartment assuming it was newly offered on the market. It tends to naturally grow over time and an energy efficiency modernization – in theory – elevates the apartment to a higher tier by the market valuation of the additional energy savings, the lower frugality costs and the market premium for the modernization costs. Therefore, the landlord gains additional revenue from the incumbent tenant that decreases over time until incumbent and future tenant pay the same. As many authors have in detail analyzed and criticized the modernization surcharge and its implementation (Braungardt et al., 2022; Bürger et al., 2013; Klinski et al., 2009; Kossmann et al., 2016; Rehkugler et al., 2014; Thomaßen et al., 2020), it is safe to assume that there are numerous barriers in the translation of the well-intended idea to place the annuity costs of the modernization onto the incumbent tenant to counter the sunk cost problem into the actual rent payments made on the German rental housing markets. Crucially, the optimal policy design of the modernization surcharge depends on the market conditions of how long the incumbent tenants remain in an apartment and how much bargaining power landlords and tenants have, which makes a universal policy parameter that sets efficient incentives across a variety of market conditions impossible to attain. Worse so, the effect of low tenant turnover is opposed to what would help achieving optimality, where the optimal modernization surcharge increases the quicker tenants change to counter the secondary landlord-tenant-dilemma.

4.6 Rent-independent modernization apportionment

An alternative to the current German modernization surcharge has been discussed by Klinski et al. (2009, pp. 198–202). The idea is to decouple the modernization surcharge from the ongoing rental contract and allowing the landlord to charge a levy even onto the future tenant. This modernization apportionment should thus be independent of the otherwise occurring development of the rent levels. Hence, the allocation system shall be called rent-independent modernization apportionment (RIMA). It is modelled with $\alpha_{RC,RIMA} = 1$ and $\alpha_{RIMA,RIMA} = 1$ and therefore very similarly to the modernization surcharge system. Instead of increasing the incumbent tenant's rent by S times the modernization costs, the factor is now called $A \in (0, \infty)$. For the future tenant, the landlord may charge an additional levy of $\frac{A \cdot C \cdot {M_{MS}}^2}{2}$, but given the assumed market for future tenants that additional levy is expected to be internalized into the agreed upon rent level. Essentially, the future tenant's effective rent payment consisting of the modernization apportionment and the agreed upon rent level should be equal to the agreed upon rent payment in the absence of the modernization apportionment. This implies that every statement derived from the model about the modernization surcharge analogously holds for the RIMA-system as they are effectively the same allocation system. However, RIMA may in practice still be socially preferable as it could alleviate the intricate and detrimental interaction with tenant turnover, implying that the legislator could more easily choose the appropriate apportionment factor. Notably, the RIMA allocation system achieves socially optimal behavior for $A = A^\star \equiv \frac{1-\beta\cdot(1-\mu)}{\mu}$. Figure 6 shows the distribution of costs and benefits for the RIMA-system where $A = A^\star \approx 1.32$. Comparing it to Figure 5 makes the two allocation systems' likeness obvious.

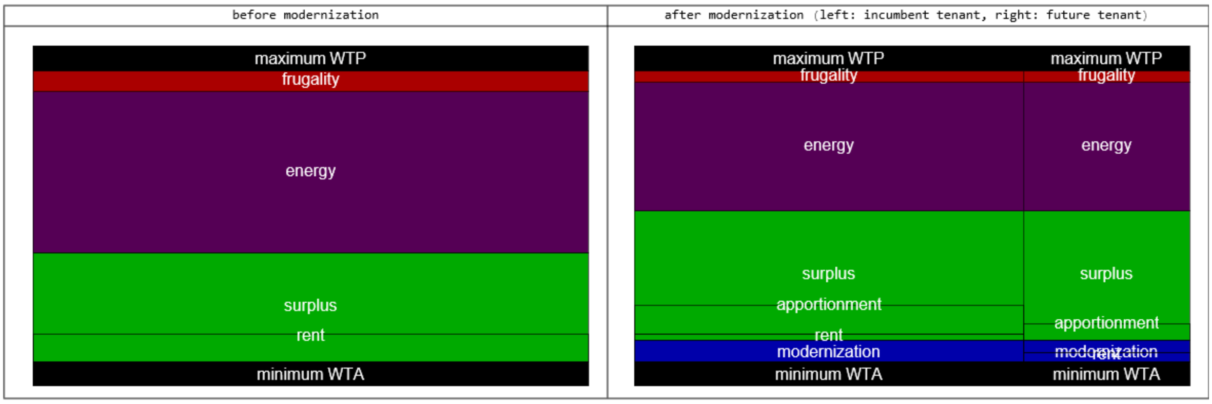


Figure 6: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the rent-independent modernization apportionment system before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level, with a second horizontal bar in the second panel showing the modernization apportionment.

4.7 Consumption based partially inclusive rent system

The consumption based (CB) partially inclusive rent system is a novel idea put forward by Braungardt et al. (2022). It is a variation of the previously discussed inclusive rent system with the alteration that neighbors within a building are incentivized to behave frugally by paying each other for deviations from the joint mean in energy consumption: those who raise the average pay to those who lower it. The payment is supposed to be facilitated by the landlord.

Within the model, this is captured by $\alpha_{IR,CB} = 1$, $\alpha_{CB,CB} = 1$ and $\alpha_{RC,CB} = 1$. The tenants' marginal energy costs are reduced by the factor $1 - \frac{1}{N}$ as a share of $\frac{1}{N}$ contributes to the average of the building. Obviously, if only one tenant occupies the entire building, no payment between neighbors may occur and the system boils down to the pure inclusive rent system. For buildings with only two dwellings, the tenant only bears half of the energy consumption he causes as the other half contributes to the mean across the building. As the number of apartments increase, the marginal energy costs depending on the tenants' behavior approaches unity. However, as I model all tenants to be homogenous, they actually all consume at the same level and thus face no real energy consumption costs. They would, on the other hand, bear marginal costs if they deviated from the average, thus having to spend frugality costs to maintain the average consumption level.

Besides this incentive to behave somewhat frugally, rent levels are determined as in the inclusive rent system: landlord and tenants agree on a rent level that covers the expected energy costs and then share the remaining welfare surplus after subtracting the expected frugality costs according to the agents' bargaining power.

The landlord's optimal modernization is given by $M_{CB}^\star \equiv \frac{P\cdot\left(N^2\cdot(\beta\cdot(1-\mu)+\mu)-P\cdot(N-1)\cdot\left((N+1)\cdot\beta\cdot(1-\mu)+2N\cdot\mu\right)\right)}{C\cdot N^2-P^2\cdot(N-1)\cdot\left((N+1)\cdot\beta\cdot(1-\mu)+2N\cdot\mu\right)} \lesseqgtr M_{SP}^\star$. Crucially, the privately optimal modernization may even be less than zero or greater than unity, which are implausible. Therefore, the forthcoming distributional analysis in Section 5 also regards those corner cases. I assume the landlord to choose the modernization $\widehat{M_{CB}^\star} \in \{M_{CB}^\star, 0, 1\}$ which maximizes her payoffs and the tenants to react accordingly.

However, the tenants' optimal consumption behavior is $B_{CB}^{post\star} \equiv 1-\left(1-\frac{1}{N}\right)\cdot P\cdot(1-M_{CB}^\star) > B_{SP}^\star$. Without having to expand the expression it can be seen that tenants react with insufficient frugality to any given modernization since $\left(1-\frac{1}{N}\right) < 1$ and thus even when the landlord coincidentally chooses the optimal modernization, the allocation system reaches suboptimal results. Figure 7 shows the distribution of costs and benefits with $N = 6$.

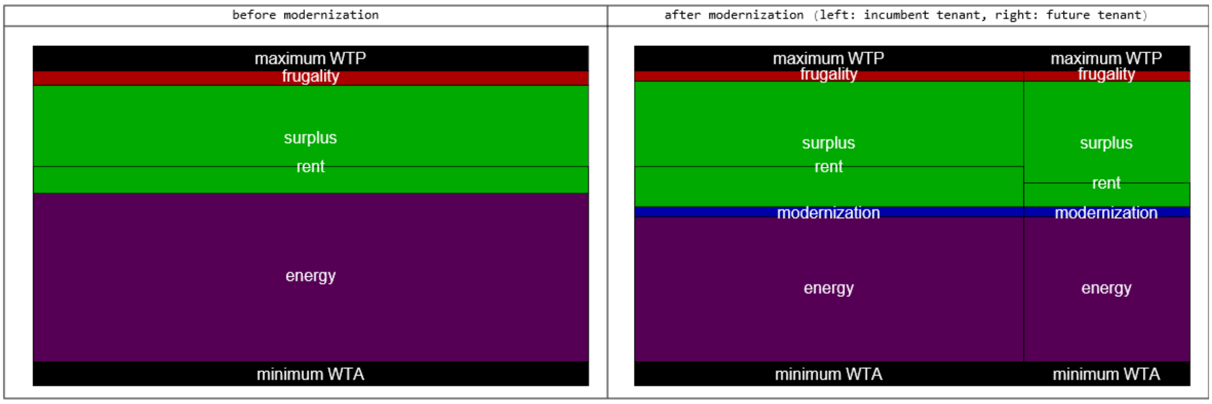


Figure 7: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the consumption based partially inclusive rent system before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The horizontal line is the agreed upon rent level.

4.8 Demand based partially inclusive rent system

The last allocation system I analyze is a novel idea developed for this paper. It tries to allocate the responsibility for the technical energy demand to the landlord and the responsibility for frugality to the tenant, thus it is called a demand based (DB) partially inclusive rent system. In essence, it is a variation of the strict rent control system with an additional payment from the landlord to the tenant. The landlord has to compensate the tenant for a demand factor $D \in (0, \infty)$ of the energy costs that would be incurred assuming comfort behavior. Of course, this compensation leads to a premium on the rent payment. After a modernization, the rent premium remains but the compensation payment decreases, thereby offering a modernization incentive for the landlord. The actual energy consumption is then paid by the tenant.

The model captures this design with $\alpha_{RC,DB} = 1$ and $\alpha_{DB,DB} = 1$. The agents optimize their payoffs by choosing a modernization of $M_{DB}^\star \equiv \frac{P\cdot\left(1+\frac{D\cdot\mu}{\beta\cdot(1-\mu)}-P\right)}{\frac{1}{\beta\cdot(1-\mu)}\cdot C-P^2} \lesseqgtr M_{SP}^\star$ and a consumption behavior of $B_{CB}^{post\star} \equiv 1-P\cdot(1-M_{DB}^\star) \lesseqgtr B_{SP}^\star$. Since tenants have the optimal marginal energy consumption costs as they pay the energy bill, they will always react optimally when the landlord chooses the socially optimal modernization. That investment proves optimal for the landlord when $D = D^\star \equiv \frac{C\cdot(1-P)}{C-P^2}\cdot\frac{1-\beta\cdot(1-\mu)}{\mu}$

which scales the socially optimal consumption behavior $B_{SP}^{\star}$ by $\frac{1-\beta\cdot(1-\mu)}{\mu}$ to balance the inefficiency caused by the sunk costs of the modernization. Figure 8 presents the distributional effects of the demand based partially inclusive rent system given optimal policy design with $D = D^{\star} \approx 1.11$.

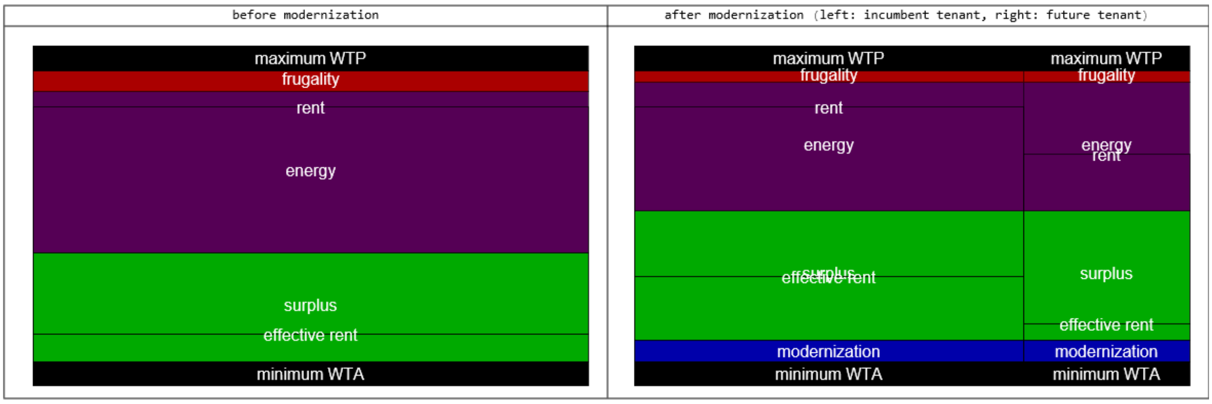


Figure 8: Distribution of costs and benefits between the landlord (bottom) and the tenant (top) via rent payments in the demand based partially inclusive rent system before and after a modernization. The black bars are the boundaries for negotiation, the red bar is the frugality costs, the purple bar the energy costs, the green bar the remaining welfare surplus and the blue bar the modernization costs. The upper horizontal line is the agreed upon rent level with the lower line being the effective rent payment after the compensation payment.

5 Welfare analysis

Now that the allocation systems have been introduced, it makes sense to compare them to one another to identify their effects on social welfare and on landlords and tenants individually. This analysis takes place in three steps. I first look at landlords' and tenants' payoffs assuming an optimal policy design, i.e. when the allocation system minimizes social costs. Here, I sample the modernization surcharge, the rent-independent modernization apportionment and the demand based partially inclusive rent system because they are the only ones from the studied allocation systems that can achieve the socially optimal outcome at all. Second, I compare the distributional effects of these optimally designed allocation systems with the consumption based partially inclusive rent system which may never minimize social costs but which treats landlords and tenants differently compared to the optimally designed allocation systems. Lastly, I study the effects of sub-optimally designed modernization surcharge and demand based partially inclusive rent systems compared to each other and to the consumption based partially inclusive rent system to assess how resilient their theoretical welfare superiority is to practical challenges to the legislator.

5.1 Distributional effects of welfare maximizing policy designs

I have shown that the modernization surcharge, the rent-independent modernization apportionment and the demand based partially inclusive rent system can minimize social costs if the respective policy variable is chosen accordingly: $S = S^{\star} = A^{\star} = A$ and $D = D^{\star}$.

Inserting these values to each allocation systems optimization and considering the constraints for C, P, μ, and α, the following preference orders can be derived:

$$L_{MS}^{\star} = L_{RIMA}^{\star} < L_{DB}^{\star} \qquad (9)$$

$$IT_{DB}^{\star} < IT_{MS}^{\star} = IT_{RIMA}^{\star} \qquad (10)$$

$$FT_{RIMA}^{\star} = FT_{MS}^{\star} = FT_{DB}^{\star} \qquad (11)$$

$$T_{DB}^{\star} < T_{MS}^{\star} = T_{RIMA}^{\star} \qquad (12)$$

The first observation is that the modernization surcharge and the rent-independent modernization apportionment yield the same results as already noted above. The second unsurprising result is that future tenants always achieve the same outcome as I assumed the market for newly formed contracts not to be infringed on by policy. This leaves two substantive results which are two sides of the same coin: (1) the cost based allocation systems (MS and RIMA) are advantageous for the incumbent tenant and (2) the demand based partially inclusive rent system favors landlords.

The intuition is as follows: in both MS/RIMA and DB, the respective policy interventions rectify the primary landlord-tenant-dilemma in the ongoing tenancies introduced by rent control limiting the landlord's ability to unilaterally increase rent levels and the secondary landlord-tenant-dilemma in the market for new tenancies due to the investment costs being sunk and thus not getting bargained over between the landlord and the future tenant. Both policy interventions alleviate the second problem by pushing the share of the modernization costs the future tenant would pay if both parties could include the investment in their bargaining onto the incumbent tenancy. As both policy approaches incentivize the landlord to modernize by offering maximum profits if she chooses the socially optimal investment, it must be the incumbent tenant who bears the share of the investment costs that should be levied onto the future tenant if the timing allowed for such contracts.

As outlined, the incumbent tenant bears the future tenant's share of the modernization costs in both the cost based approaches and the demand based partially inclusive rent system. This leaves the distributive difference between the approaches to explain by how they allocate the modernization's costs and benefits that accrue during the incumbent tenancy between the parties.

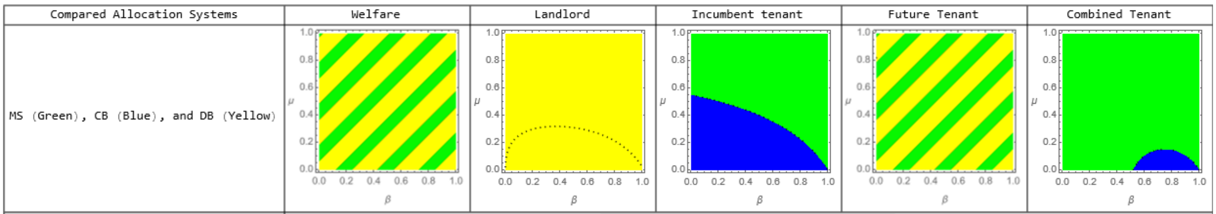
For that portion of the modernization's costs and benefits, the cost based approaches ideally allocate exactly the modernization costs for as long as rent control is effective onto the incumbent tenant. This leaves the entire welfare surplus generated by decreased energy and frugality costs with the tenant. The landlord only profits from the incumbent tenant by the share of the modernization costs that she later on cannot gain from the future tenant.

The optimally designed demand based partially inclusive rent system, however, allocates more than the welfare surplus the modernization generates during the ongoing tenancy to the landlord on top of the future tenant's share of the modernization costs. The reason for the demand based partially inclusive rent system benefitting the landlord over the incumbent tenant is that the optimal demand factor $D^{\star} = B_{SP}^{\star} \cdot \frac{1-\beta\cdot(1-\mu)}{\mu} > B_{SP}^{\star} = B_{DB}^{\star} > B_{DB}^{pre}$ equals the socially optimal consumption behavior in the modernized apartment scaled up to accommodate the issue of the sunk costs. Abstracting from the issue of sunk costs, the allocation system places financial responsibility onto the landlord equal to those energy costs that an occupant would accrue if they behaved as frugally as if the apartment was optimally modernized in any given apartment. In the not yet modernized apartment, the tenant actually behaves more frugally, yielding less energy consumption costs than the compensation payment. It is only at the socially optimal modernization that the actual energy costs and the compensation payment coincide. Until then, the rebound effect where the modernization substitutes frugality means that the tenant's actual savings in energy and frugality costs will be lower. Due to the social optimality of the modernization, the combined energy cost savings and frugality cost savings already exceed the modernization costs, so the allocation system induces the landlord to be better off and the incumbent tenant to be worse off than if both parties shared the modernization costs, the energy cost savings, and the frugality cost savings according to their bargaining power. The demand based partially inclusive rent system thus places the rebound effect and hence the effects of a modernization on frugality solely onto the tenant. As the optimal demand factor scales by the magnitude of the inefficiency caused by the sunk costs for future markets, this distributive effect where the landlord benefits from the incumbent tenant's frugality in the not yet modernized apartment is amplified when landlords are weak or when there is a quick turnover of tenants.

5.2 Welfare and distributional effects of the sub-optimal consumption based partially inclusive rent system compared to optimally designed allocation systems

As shown in the previous section, the two cost based allocation systems (MS and RIMA) and the demand based partially inclusive rent system (DB) can achieve the socially optimal outcome and thus even outperform the idealized free market if designed optimally. However, they have different distributional effects. In this next section, I focus on the welfare and distributional effects of these allocation systems compared to the consumption based partially inclusive rent system (CB), which always yields suboptimal outcomes in terms of social costs but is another politically relevant option.

The comparison between the optimally designed MS and DB systems with the suboptimal CB system is displayed in Figure 9 as plots in the β-μ-plane which describes every rental market conditions within my model. The graphs show which of the three allocation systems MS, CB, and DB performs best for overall social welfare, for the landlord's payoffs, and the incumbent, future and combined tenant's payoffs. The hatched plots for welfare and future tenant indicate that the modernization surcharge and the demand based partially inclusive rent system equally achieve the socially optimal incentives whereas the consumption based partially inclusive rent falls short. As outlined above, the optimally designed DB benefits the landlords while the optimally designed MS benefits the incumbent tenant and thus the combined tenant.

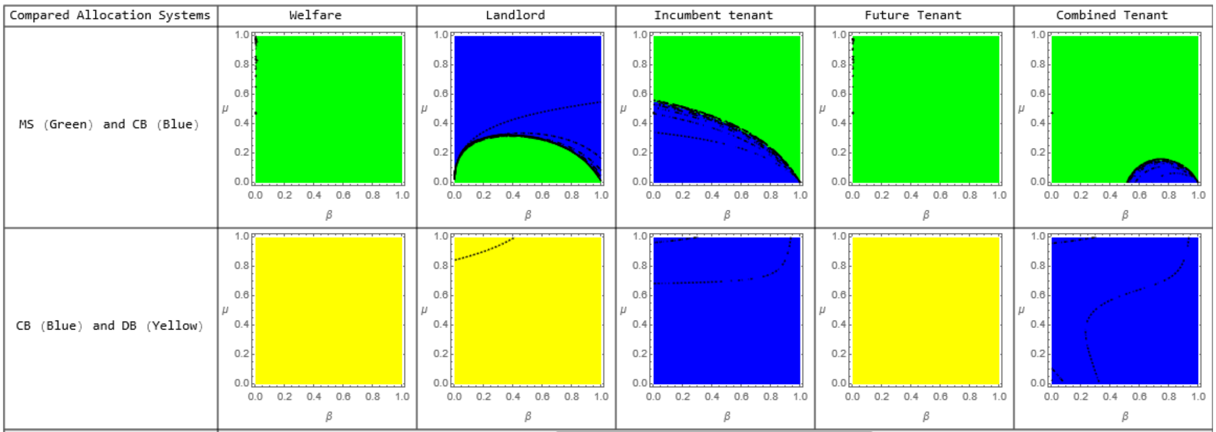


Parametrization

Variable	Value
$\hat{R}$	0.3
C	0.7
P	C×0.3=0.21
S	$S^* = \frac{1-(1-\mu)\beta}{\mu}$
N	6
D	$D^* = \frac{1-(1-\mu)\beta}{\mu} \times \frac{C-CP}{C-P^2} = \frac{1-(1-\mu)\beta}{\mu} \times 0.843$

Figure 9: Distributional effects of the three studied allocation systems: the optimally designed modernization surcharge (MS), the consumption based partially inclusive rent system (CB), and the optimally designed demand based partially inclusive rent system (DB). Colored area within each plot shows the region in the β-μ-plane where one allocation system performs better than the others in terms of overall welfare, and the landlord's, the incumbent tenant's, the future tenant's and the combined tenant's payoffs. MS is shaded in green, CB in blue, and DB in yellow. The hatched plots indicate that the two corresponding systems are equally good and outperform the other. Dotted line indicates equality between MS and CB, dashed line between MS and DB, and full black line between CB and DB. The bottom table reports the parametrization.

However, the difference in distributional effects between the modernization surcharge and the consumption based partially inclusive rent system depends on the market conditions. When incumbent tenants have little weight and landlords are weaker, the consumption based partially inclusive rent system tends to benefit incumbent tenants. This effect may even be strong enough to overcome the overall welfare sub-optimality for the combined tenant when tenancies are very short and the landlord's bargaining power is rather large. On the other hand, CB benefits landlords compared to MS when tenancies are rather long. Figure 10 shows that smaller buildings weaken both effects, i.e. for smaller buildings MS creates better results for landlords for longer tenancies and better results for incumbent tenants when tenancies are shorter.



Parametrization

Variable	Value
$\hat{R}$	0.3
C	0.7
P	C×0.3=0.21
S	$S^* = \frac{1-(1-\mu)\beta}{\mu}$
N	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}
D	$D^* = \frac{1-(1-\mu)\beta}{\mu} \times \frac{C-CP}{C-P^2} = \frac{1-(1-\mu)\beta}{\mu} \times 0.843$

Figure 10: Effects of variance in building size N on the distributional effects of the consumption based partially inclusive rent system (CB) compared to the optimally designed modernization surcharge (MS) and the optimally designed demand based partially inclusive rent system (DB). Colored area within each plot shows the region in the β-μ-plane where one allocation system performs better than its comparative partner's in terms of overall welfare, and the landlord's, the incumbent tenant's, the future tenant's and the combined tenant's payoffs. MS is shaded in green, CB in blue, and DB in yellow. Dashed lines indicate increases in N compared to the initial condition with longer dashes representing higher values. Dot-dashed lines mean decreases with decreasing dashing length corresponding to decreasing values. The bottom table reports the parametrization with the highlighted row indicating the changing variable.

Intuitively, the consumption based partially inclusive rent system incentivizes tenants to behave less frugally both before and after the modernization. Since the landlord's benefits from the modernization accrue via the energy cost savings she gains during the incumbent tenancy after a modernization, the diminished frugality actually benefits the landlord: the monetary energy cost savings of a modernization are greater if the tenant consumes relatively more energy compared to the social optimum. Therefore, the landlord benefits from larger modernization effects when tenancies are longer and the incumbent tenant benefits from less frugality costs albeit only for a short period after the modernization. However, that effect is countered by the overall inefficiency of the insufficient frugality incentive. That is why MS tends to provide better outcomes for both the landlord and the incumbent tenant if buildings are very small and thus an excessive modernization is chosen in response to insufficient frugality.

Comparing CB to DB, the general inefficiency of the insufficient frugality incentive can mean better outcomes for incumbent and combined tenant in the otherwise landlord friendly demand based partially inclusive rent system when buildings only have two apartments. In contrast, when incumbent tenancies are very long, the aforementioned effect of the landlord benefitting from the greater relative energy cost savings from the modernization prevails over the efficiency of the demand based partially inclusive rent system.

5.3 Welfare and distributional effects of sub-optimally designed allocation systems

At last, the effects of changing the modernization surcharge factor S and the demand factor D must be examined. Assuming optimal design, both depend on the market conditions, i.e. the duration of the incumbent tenancy and landlord's and tenant's bargaining power. In a real setting, it appears implausible to assume that these legal parameters can be designed to variably change depending on the local market conditions, not to mention that in the model costs are normalized to the occupant's marginal discomfort from frugality, hence the policy might even have to address the tenants' variance as well. Instead, it is most plausible to assume that the legislator estimates one value that holds for the entire country. This estimate could aim specifically at edge cases of the market conditions or at rather moderate values. As outlined above, choosing a global value for S is difficult due to the interaction of the modernization surcharge with tenant turnover, whose effect is hard to predict. Nonetheless, Figure 11 reports the effects of such globally chosen constant policy variables when comparing the three allocation systems in question. Note that $D = \frac{C\cdot(1-P)}{C-P^2} \cdot S \approx 0.843 \cdot S$ for the arbitrarily chosen values of $C = 0.7$ and $P = 0.21$. This highlights how both optimal policy variables linearly depend on the same fraction $\frac{1-\beta\cdot(1-\mu)}{\mu}$ to balance the secondary landlord-tenant-dilemma cost inefficiency while the demand factor D is also scaled by the socially optimal consumption factor $B_{SP}^{\star} = \frac{C\cdot(1-P)}{C-P^2}$.

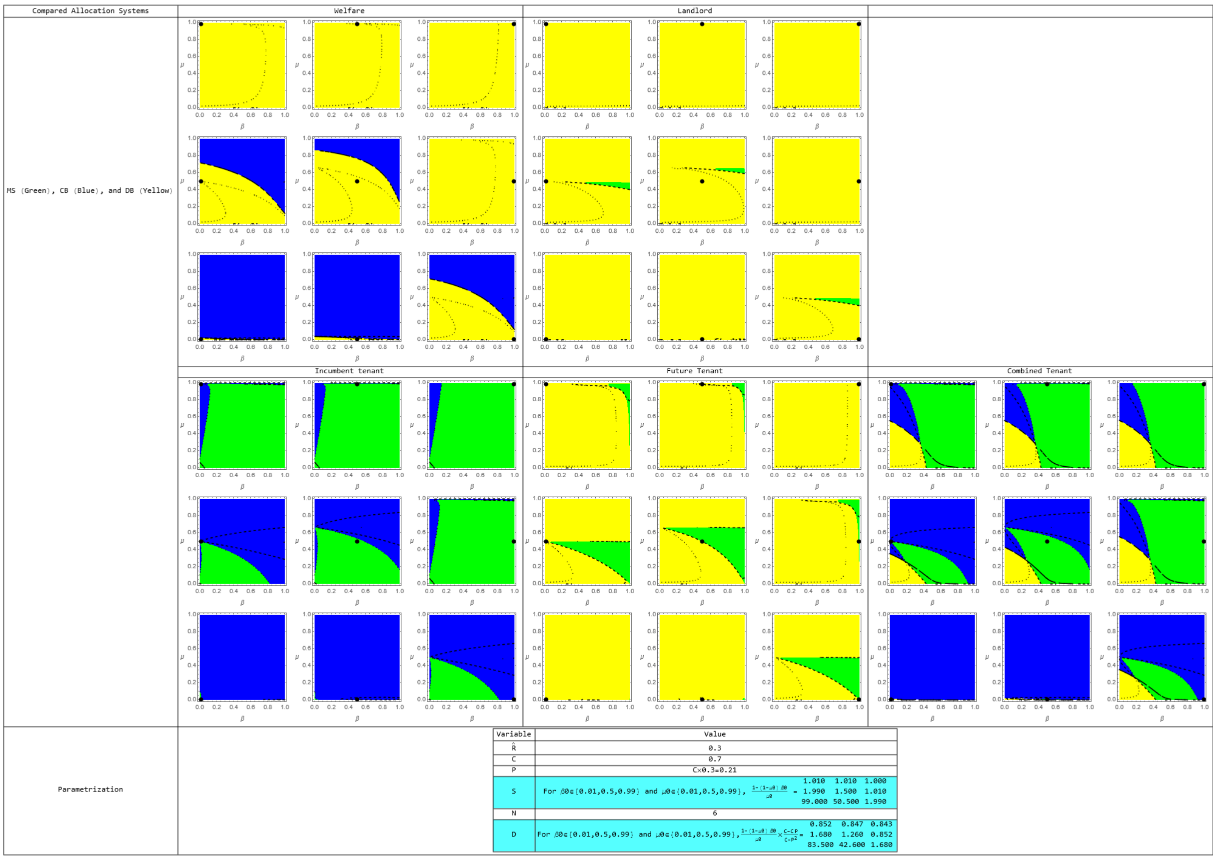


Figure 11: Distributional effects of globally chosen policy variables (modernization surcharge factor S and the demand factor D). Colored area within each plot shows the region in the β-μ-plane where one allocation system performs better than the others in terms of overall welfare, and the landlord's, the incumbent tenant's, the future tenant's and the combined tenant's payoffs. MS is shaded in green, CB in blue, and DB in yellow. Dotted line indicates equality between MS and CB, dashed line between MS and DB, and full black line between CB and DB. The bottom table reports the parametrization. The large black dot indicates for which market condition the legislator chose the optimal policy variable.

Looking at the welfare effects, it can be seen that the modernization surcharge never achieves better results than the other two allocation systems while DB achieves best results when the demand factor is less than unity. For greater demand factors, chosen to accommodate markets with shorter incumbent tenancies and weaker landlords, the consumption based partially inclusive rent system achieves better results when tenancies are longer or landlords are stronger. The intuition is quite simple: excessive modernization incentives to accommodate markets with greater inefficiencies caused by the secondary landlord-tenant-dilemma lead to wildly excessive modernizations in markets where the main driver of inefficiency is general rent control. On the other hand, choosing the policy variable to accommodate markets with long tenancies makes sense as the model assumes that tenancy law cannot meaningfully alleviate the sunk cost issue beyond shifting the future tenant's share in modernization costs onto the incumbent tenant. In that regard, the rental markets with short tenancies and weak landlords are more or less a lost cause for setting efficient modernization incentives via tenancy law.

Looking at the distributional effects, the aforementioned general trends persist with global policy variables: DB tends to benefit landlords with the other two systems favoring incumbent tenants. In their regard, the modernization surcharge achieves better results when the modernization surcharge factor does not wildly exceed unity, prompting excessive modernization incentives for markets where a smaller modernization surcharge would suffice due to the longevity of the incumbent tenancy.

The plots for the future tenants' payoffs echo the considerations on general welfare, with the notable difference that its inherent inefficiency bars the consumption based partially inclusive rent system to be beneficial in any market condition. Looking at the combined tenant, the balance between general efficiency as more reliably achieved by the demand based partially inclusive rent system and rather tenant friendly design by the other two allocation systems can be easily seen.

6 Conclusions and policy recommendations

The German rental building sector is a major emitter of greenhouse gases. This is in part due to inefficient incentives from the landlord-tenant-dilemma, which should be thought of as a primary and a secondary landlord-tenant-dilemma, with the primary resulting from rent control in tenancy law and the secondary from the issue of sunk modernization costs when landlord and prospective tenant bargain over rent levels. The primary landlord-tenant-dilemma can directly be addressed by allocation systems for energy and modernization costs within tenancy law while the secondary dilemma can only indirectly be influenced by shifting a greater share of modernization costs onto the incumbent tenant. This paper analyzed several allocation systems using a microeconomic model to understand how these allocation systems incentivize landlords to modernize and tenants to behave energy consciously. The idealized market sets insufficient modernization incentive with strict rent control exacerbating the problem. An inclusive rent system tends to overemphasize modernizations. The modernization surcharge can be designed to universally induce optimal behavior by making the incumbent tenant pay for exactly his and the future tenant's share of the modernization costs while accruing the entire energy and frugality cost savings. The rent-independent modernization apportionment works functionally alike as the market for future tenancies can be assumed to internalize the modernization apportionment that may be levied onto the future tenant. The novel demand based partially inclusive rent system may also be setup to induce optimal behavior. A consumption based partially inclusive rent system as modelled may never achieve the socially optimal outcome.

Assuming optimal policy design, the cost based approaches of the modernization surcharge and the rent-independent modernization apportionment favor the incumbent tenant who accrue the entire welfare surplus generated by the modernization (energy and frugality cost savings vis-à-vis the investment costs). The demand based partially inclusive rent system, on the other hand, tends to benefit the landlord who is guaranteed a share of the modernization's cost savings that exceeds the share she would get on the free market. Both approaches naturally suffer from imperfect parametrization by the legislator, yielding inefficient results when the relevant policy variable is chosen poorly. However, the demand based partially inclusive rent system is more resilient to a poorly chosen target market by the legislator.

The modernization surcharge, albeit generally more favorable to tenants, tends to provide a lot of security to landlords: they are guaranteed to recoup their investment costs during the ongoing tenancy while only benefitting from the energy and frugality cost savings once a new tenant bargains over rent levels. Furthermore, the tenant solely bears the energy price risk: as he is the one to pay for the energy costs, unforeseen price increases as for instance happened after Russia's invasion of Ukraine, directly hit the tenant while triggering only little changes in the landlord's optimization decision. In other words, the modernization surcharge leaves the benefits of the modernization with the tenant but also the enduring costs if no modernization takes place. The demand based partially inclusive rent system, however, holds the landlord more directly accountable for the energy costs the building faces. It thereby offers greater benefits for the modernizing landlord while also giving her some share of the energy price risk. Furthermore, as the landlord's benefits are driven by the modernization's effects, not the modernization costs, the demand based partially inclusive rent system runs less risks of incentivizing a wildly excessive modernization. This may occur in the modernization surcharge with a slightly excessive cost factor and a large weight of the incumbent tenants where the landlord can rely on generating profits from the modernization due to its costs with little regard to the modernization's effects. The demand based partially inclusive rent system thus appears a bit more robust than the modernization surcharge.

Two mutually exclusive policy recommendations for the German legislator can be drawn from the model analysis in this paper: a case for adjusting the cost based approach of the modernization surcharge and a more radical case for the introduction of the demand based partially inclusive rent system. The former requires the legislator to make sure that the incumbent tenant pays exactly for the modernization costs regardless how long he stays in the apartment. The current design that allows the landlord to demand a one-time rent increase whose additional rent revenue decreases over time due to the interaction with the rent customary in the locality can only by mere chance set the appropriate surcharge factor. The additional rent revenue does not just depend on the expected duration of the ongoing tenancy and the size of the initial rent increase but also on the conditions of the local rental market which vary wildly across the country. Therefore, the legislator should implement a system where the additional rent revenue from the incumbent tenant is more steady over time and equal to the annuity cost of the modernization scaled by a factor that accounts for the expected duration of the tenancy. This reformed modernization surcharge should be decoupled from the reference rent system. Whether this reformed modernization surcharge should also be applicable to future tenancies as in the rent-independent modernization apportionment requires further study. Here, the question is whether the additional policy intervention in the negotiation of a new rental contract helps alleviating market imperfections or only causes additional transaction costs for landlords and prospective tenants.

The second policy recommendation is more radical, that is the introduction of the demand based partially inclusive rent system. In a first step, it requires widespread energy demand certificates which are not yet ubiquitous. However, the 2024 recast of the EU Energy Performance in Buildings Directive (EPBD) requires the member states to adopt demand based energy performance certificates anyway (Article 4 and Annex I). The second step is to determine the appropriate demand factor. Here, the legislator should base the decision on thorough engineering- and data-driven analysis to estimate A) the optimal energy demand of the representative building in the building stock, B) the optimal consumption factor for a representative occupant, and C) the average market conditions in terms of length of tenancy and distribution of bargaining power. Once these estimates are available, tenancy law can be changed. However, initial simulations in this paper showed that the demand based partially inclusive rent system tends to achieve almost universally best welfare effects when the demand factor is close to but not more than unity. The policy change could perhaps be implemented by only changing the legal framework for utility billing without having to change every rental contract. However, the exact implementation pathway requires further legal research. It furthermore has to be ensured that the landlords actually pay the right reimbursement every year. This radical system change obviously entails high learning and transaction costs for everybody involved in the rental housing sector. However, the benefit of a more robust modernization incentive that distributes the risk of energy price changes among landlords and tenants could outweigh these transaction costs.

Future research based on the model developed in this paper should loosen three key assumptions I made to maintain analytical clarity: the first being that modernizations are always socially preferable. This assumption pertains to the distributional effects of excessive modernization incentives in each allocation system, where a modernization may be financially viable for the landlord although it causes greater investment costs than energy and frugality cost savings, necessarily leaving the tenant worse off. It would be interesting to scrutinize the allocation systems as to which one is more susceptible to this allocative mistake. A second possibly interesting extension would be explicitly modelling the internalization of the climate change externality via subsidies, carbon pricing, or regulatory law and how this changes the distributional effects of each allocation system. Lastly, a more detailed analysis of the period of tenancy law change and the ensuing distributional effects would be interesting but was beyond the scope of this paper. Pursuing this issue would also require more thorough thought on the demand and supply elasticities on the rental housing market in light of changing tenancy law.

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7 Appendix

Table 2: Nomenclature

Optimization variables: agents' behavior		
Symbol	Domain	Meaning
M	$[0,1]$	Modernization where 1 is a full retrofit without any further energy demand
B	$(0,\infty)$	Occupant's heating behavior where 1 is heating every room to comfort level
Exogenous variables: model inputs		
Symbol	Domain	Meaning
P	$(0,C)$	Costs for heating every room of the un-modernized building to comfort level
C	$(0,1)$	Cost factor for modernizations
β	$(0,1)$	Landlord's bargaining power
μ	$(0,1)$	Incumbent tenant's weight in the calculus
S	$(0,\infty)$	Modernization surcharge factor, i.e. factor of the modernization costs that may be levied on incumbent tenants
A	$(0,\infty)$	Modernization apportionment factor, i.e. factor of the modernization costs that may be levied on incumbent and future tenants
N	$\mathbb{N}$	Number of apartments in the building
D	$(0,\infty)$	Energy demand factor, i.e. share of the current energy demand costs that the landlord has to compensate tenants for, assuming comfort behavior
$\alpha_{1,\sigma} \dots \alpha_{6,\sigma}$	$\{0,1\}$	Specifications of allocation system i
Endogenous variables: agents' wellbeing and transfers		
Symbol	Range	Meaning
W	$\mathbb{R}$	Social welfare, i.e. combined wellbeing of the landlord and tenants
L	$\mathbb{R}$	Landlord's wellbeing
T	$\mathbb{R}$	Tenants' wellbeing, i.e. weighted combined wellbeing of incumbent and future tenants
IT	$\mathbb{R}$	Incumbent tenants' wellbeing
FT	$\mathbb{R}$	Future tenants' wellbeing
R	$(0,\hat{R})$	Nominal rent payment
Superscripts: attributes to variables		
Symbol		Meaning
$\star$		Optimal value of a variable derived from first order conditions
pre		Before the modernization
$post$		After the modernization
Accents: signifiers for variable states		
Symbol		Meaning
$\hat{}$		Maximum value
$\tilde{}$		Average / expected value; only applies to consumption behavior
Subscripts: signifiers for allocation systems		
Symbol		Meaning
SP		Social Planner
FM		Free market
RC		Rent control market

IR	Inclusive rent market similar to the Swedish status quo
MS	Modernization surcharge similar to the German status quo
$RIMA$	Rent-independent modernization apportionment similar to the proposal analyzed by Klinski et al. (2009)
CB	Consumption based partially inclusive rent system similar to the proposal analyzed by Braungardt et al. (2022)
DB	Demand based partially inclusive rent system, newly proposed by the author
σ	any of these subscripts: $\sigma \in \{SP, FM, RC, IR, MS, RIMA, CB, DB\}$