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CESIFO WORKING PAPER NO. 6146
CATEGORY 12: EMPIRICAL AND THEORETICAL METHODS
OCTOBER 2016

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ISSN 2364-1428

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Abstract

The Coordination Reform was introduced in Norway in 2012 including a fee for bed-blocking in hospitals. To study this, we introduce a Stackelberg game where the hospital is the leader and the care institution is the follower. The reform does not necessarily lead to less bed-blocking as this depends on the relative strength of the players' concern for income and patients' health, and the optimal discharge date before the reform. Testing the results with data, we find a large negative effect on bed-blocking and discharge date. Thus, financial incentives may count more than health incentives, or health effects of bed-blocking are insignificant.

JEL-Codes: H750, I110, I180.

Keywords: bed-blocking, care services, hospital services, health reform, Stackelberg game.

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October 2016

This paper is part of the project “Evaluation of the Coordination Reform” funded by the Research Council of Norway. We are indebted to comments from Albert Ma, Tor Iversen, Andreas Kotsadam, Lone Grønbæk, other participants in the project, and seminar participants at HERO, Frisch Centre, NMBU, Bergen University College, University of Southern Denmark, and the National Health Economic Conference.

1. Introduction

Long term care can be provided in different ways such as by family, hospitals as well as by nursing homes and community nursing. Thus different providers of care may meet the patients' need for care, and the organization of long term care also varies for different countries (see e.g., Herolfson and Daatland, 2001; Daatland, 2001). This does not necessarily mean that all types of care such as formal and informal care are complete substitutes,⁴ but to some extent there is substitution between different care services.

How the supply of care in a society is organized may depend on Governmental preferences for instance whether the Government wants a large labour supply by making it possible to combine care giving with participation in the labour market. Community nursing may be one example of this where parts of the care is given by home visits of care personnel employed by the municipality. Financial incentives may also play a role. Even if there is a comprehensive system for publicly provided care for elderly and disabled individuals, we cannot rule out that these incentives matters for the services provided as long as care institutions are restricted by given budgets.

The organization of care services may however not always be optimal due for instance to different institutional barriers. If a supplier is chosen that offers care at a higher cost than other suppliers without doing better on patient health or welfare, there is an efficiency loss for the society. Or alternatively, if a supplier is chosen that can compete on costs but will not give the same welfare or health improvements for patients, there may also be a social cost. One concern of social inefficiency that has attracted a lot of attention over some decades is delayed discharge in hospitals for patients in need for care services (see Rubin et al., 1975, for an early study). Delayed discharge leads to bed-blocking, which occurs when patients who have completed treatment at a hospital and is waiting for admittance to a nursing home or home care, remains at the hospital (Mur-Veeman and Govers, 2011). Bed-blocking may give a social cost if it increases waiting time for new patients, if care costs are lower in nursing homes or at home, and if the health consequences for the patient are low or even negative due to, e.g., susceptibility to new infections.⁵

⁴ Many relatives may for instance view publicly provided care as insufficient to meet the needs of the patient, particularly with respect to coverage of social needs.

⁵ The reasons for bed-blocking are diverse such as internal hospital delays, or waiting for social care assessment, funding or housing, see, e.g., Glasby et al. (2004;2006).

In this paper, we study how economic incentives matter for the organization of care when care can be provided by both hospitals and community nursing homes. The starting point for studying this is the Coordination Reform that was introduced in Norway in January 2012. One of the main goals of the reform was to introduce a more effective organization of care services by changing the incentives so that agents in the system to a larger extent would consider the consequences of their actions on other institutions. The Norwegian municipalities were affected by two main new incentives. First, to stimulate investment in preventive measures, the municipalities have to pay the hospitals 20% of the costs of treatment of a set of somatic diseases for their inhabitants.⁶ Second, to reduce bed-blocking, the municipalities have to pay the hospitals a daily fee of NOK 4,000 (2012)⁷ for patients who are ready to be discharged to municipal care services, but unable to leave because the municipalities do not provide the necessary services. The hospitals have to notify the municipalities in advance of patients who need municipal services, and the fee applies from the first day the patient is considered ready to be discharged. In addition to this, the budgets of hospitals and municipalities were adjusted to compensate for the effects of the fee such that there was an increase in the municipal budgets and a decrease in the budgets of the hospitals.⁸ Before 2012, there was no fee until the tenth day after the patient was ready to be discharged. The fee was also lower, and it was often not applied since the hospitals were not required to do so.

In this paper, we study the second incentive of the reform, namely the introduction of a fee for bed-blocking in hospitals. By assuming that patients can receive similar services for a certain time period in both hospitals and care institutions, we can analyse how this economic incentive affects the decisions of hospitals and care institutions. We do this by first introducing a Stackelberg game where the hospital is the leader and the care institution is the follower. The hospital decides on the discharge date (or the treatment time), taking into account the reactions of the care institution. The model shows that the introduction of a fee does not necessarily lead to less bed-blocking. For the care institution, a higher fee gives an incentive to reduce time at the hospital, while a higher budget gives an incentive the other way around. A higher fee has indeterminate effects on the discharge date for the hospital as it

⁶ This was terminated January 1 2015.

⁷ The fee has been adjusted annually and was NOK 4,505 in 2016, approximately 490 Euro (August 2016).

⁸ In 2012, NOK 560 million (around 60 million Euro) were transferred from the hospitals budgets to the municipalities so that the municipalities should be able to offer suitable care to the patients after discharge from the hospital. Note that this was only part of the budget transfer from hospitals to municipalities, as the other part of the reform also involved transfers (<https://www.regjeringen.no/no/tema/helse-og-omsorg/helse--og-omsorgstjenester-i-kommunene/samhandlingsreformen-i-kortversjon1/id650137/>).

depends on the relative strength of the hospital's concern for patients' health and income. If the health effect of bed-blocking is insignificant, the treatment time will go down. This will be the case if the treatment time is high without the fee and additional hospital treatment has marginal health effects. This is also supported by lower hospital budgets. A lower treatment time may, however, give an incentive for the care institution to let the patient stay longer at the hospital if hospital treatment has a positive health effect. This may partly outweigh the effect of the tax. The model demonstrates the importance of considering the strategic behaviour of the hospital when evaluating the policy change.

The empirical importance of this mechanism is assessed in the second part of the paper where we use data on the policy reform to estimate the effect of introducing fees on bed-blocking and the accompanying budget changes, and to what extent the effects were affected by the new incentives to behave strategically. The conclusions are that the reform had a large effect in terms of reducing bed-blocking. The total number of bed-blocking days was for instance reduced by 58% from 2011 to 2012. The treatment time was also significantly reduced. Considering the hospitals' strategic behaviour in reducing the discharge date and increasing the number of patients that were reported to be ready for discharge, the effect of the fee becomes significantly large. The empirical results combined with the theory model indicate that the treatment time at the hospital was high before the reform, i.e., the discharge date was set in the upper part of the relevant interval. Reduced treatment time would, therefore, have minor negative health effects, which is confirmed by data on readmission to hospitals (Hagen et al. 2016).

There is an existing literature on the effects of measures to reduce bed-blocking. For non-financial incentives, Mur-Veeman and Govers (2011) find that setting up intermediate care departments in hospitals to reduce bed-blocking is not sufficient and bed-blocking is often caused by lack of buffer management. This is hampered by lack of cooperation between care providers. Fees for bed-blocking was first introduced in Scandinavia. Sweden introduced a reform in 1992 that placed economic responsibility for bed-blockers on municipalities. According to Styrborn and Thorslund (1993), bed-blocking went down, but it was hard to identify the effect of the fee, as other factors were also involved. Denmark introduced the fee in 1993, but it was not made mandatory (Colmorten, et al., 2003). Still, there has been a decrease in bed-blocking since 1993. A large health reform in 2007 also made some changes to this arrangement, and a fee of about DKK 2000 (about half the size of the Norwegian fee)

was now made mandatory. The effect on bed-blocking has, however, been limited (Grimsmo and Magnussen, 2015). As mentioned above, Norway had a fee for bed-blocking before the Coordination reform, introduced in 1999, but this was not introduced in all hospitals. Using a natural experiment due to changes in catchment areas for hospitals, Holmås et al. (2010) find that monetary incentives crowd out agents' motivation leading to reduced effort in reducing bed-blocking compared to the cases where there were a closer cooperation without punishment. A fee for bed-blocking was also introduced in England in 2003 (The Community Care Act). The fee was set to £100 per day (£120 in south-east England), but it was introduced together with several other measures (Manzano-Santella, 2010). Godden et al. (2009) find that there is little evidence to conclude that the introduction of the fee has increased public sector efficiency even if there has been a small overall reduction in delayed discharges. McCoy et al. (2007) suggest that the investments arising from grants (the Delayed Discharge Grant) were more effective than the delayed transfer fee. Most hospitals chose not to charge the fee, but use the grant to fund interventions to reduce delays in discharge. Many patients experienced the hospital discharge negatively, and it has been an increase in the readmissions in hospitals (Bryan, 2010).

The most relevant comparisons to the Coordination Reform are the Danish system and the Community Care Act in England. However, as seen from the results above, they are not directly comparable as the fee was lower in both countries⁹, and several other measures were introduced at the same time in England. In addition, the hospitals in England used the fee to a lesser extent than in Norway. Thus, we also find higher effects of the fee in Norway than was found in England and Denmark. Our study brings an additional contribution to this field as it analyses the strategic decisions taken by the hospital and the care institution as a game where they have to consider both income and health effects.

In the next section we set up the game between hospitals and care providers and give predictions of the results of the reform in Section 3. These predictions are tested in Section 4, while the final section concludes.

⁹ Denmark plan to increase the fee to be similar to the Norwegian size from 2017.

2. A game between a hospital and a care provider

Below, we introduce a game between a hospital and care providers to study the strategic incentives of the different providers of care services. Both providers of services care about the health of the patient. Let the health of a representative patient be described by the following function

$$(1) \quad h = h(x^H, x^C, \delta)$$

where $h'_{x^H} \geq 0, h'_{x^C} \geq 0, h'_{\delta} < 0$.

h is the level of health, x^H is the level of hospital services and x^C is the level of care services provided by the municipality. Both hospital and care services can be interpreted as days at the institution or the use of other costly resources. Health is increasing in services but falling in need factors, δ , such as age, prevalence of long-term conditions, rate of informal care etc.

Note that the individual can only receive one service at the time; either it is in hospital and receives hospital services, or it receives care services from its local community.

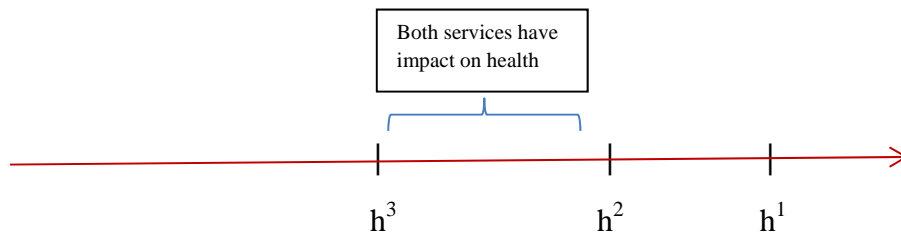


Figure 1: The health thresholds of an individual

Assume now that the individual needs care services if the health level is below a certain value; h^1 . There is also another threshold value, h^3 : if $h < h^3$ where $h^3 < h^1$, hospital services are needed and it would violate medical ethics not to provide health services if the health level is below this level.¹⁰ In this case, care services will not improve the health of the individual, and we assume that no such services are given. Likewise, if $h > h^2$, where $h^2 < h^1$, there is no

¹⁰ There is of course also a lower limit to when hospital services are needed, defined by the health level necessary to live.

need for hospital services, and they will, therefore, have no impact on the health level.¹¹ Thus, in the interval $h^2 < h < h^1$, only care services from the municipality can improve the health of the individual and no hospital services are, therefore, given. However, there is also an interval described by $h^3 \leq h \leq h^2$, where the medical situation is such that both hospital and care services have a positive impact on health, however, not necessary in the same way as one may be more productive than the other. This interval gives a room of freedom for hospitals to decide when to discharge patients. This is illustrated in Figure 1.

Based on this, we can specify the properties of the health function in more detail:

$$h'_{x^H} > 0 \text{ and } h''_{x^H, x^H} < 0 \text{ for } h \leq h^2, h'_{x^H} = h''_{x^H, x^H} = 0 \text{ for } h > h^2.$$

$$h'_{x^C} > 0 \text{ and } h''_{x^C, x^C} < 0 \text{ for } h^3 \leq h < h^1, h'_{x^C} = h''_{x^C, x^C} = 0 \text{ for } h < h^3 \wedge h \geq h^1.$$

If hospital services are given when the health level is close to h^3 , they will have a large marginal effect on health. This effect will, however, be lower the closer the health level is h^2 . This will be important in the interpretations of the results below, and we will refer to Figure 1 in these interpretations.

In addition, we assume that hospital and care services are technical substitutes at the margin, i.e., $h''_{x^H, x^C} = h''_{x^C, x^H} < 0$ for $h^3 \leq h \leq h^2$, meaning for instance that for a higher level of hospital services provided, the effects of additional care services would have lower impact on health.

It follows from the discussion above that there is no exact medical answer to when the patients should be transferred from the hospital to the care institutions. The question we would like to study is, therefore, for what health level would the hospital like to discharge their patients? To study this, we need to say something about the decision structure in hospitals and by care providers.

Inspired by Forder (2009), we assume that the preferences of the hospital and care institution can be described by the following utility functions:

¹¹ In some cases, the health effect of staying at the hospital may even be negative as there is a risk of being introduced to new infections.

$$(2) \quad U^j = u^j(n \cdot h(x^H, x^C, \delta), m^j), j = H, C$$

where $U_{nh}^{j'} > 0, U_{m^j}^{j'} > 0, U_{nh,nh}^{j''} < 0, U_{m^j,m^j}^{j''} < 0, U_{nh,m^j}^{j''} = U_{m^j,nh}^{j''} = 0$.¹²

However, as opposed to Forder (2009), x^H and x^C cannot be used at the same time by the representative individual.

Let n be the number of patients who are living in a care institution or some kind of sheltered housing, and assume that all patients are equal. Thus, $n \cdot h(\cdot)$ is the sum of welfare of all patients. Further, m^j describes the financial situation for the agent, where a better financial situation (e.g., a budget surplus) has a positive impact on the utility. Thus, the agent faces a trade-off between the welfare of the patient and its financial situation.¹³

The budget constraints for the hospital and the care institution can be outlined as follows:¹⁴

$$(3) \quad m^H = B^H - p^H \cdot nx^H + t \cdot nx_t^H$$

$$(4) \quad m^C = B^C - p^C \cdot nx^C - t \cdot nx_t^H$$

where B^j is the budget of the agent, which may also describe its capacity constraint, and p^j is the unit cost of providing the service, for instance net of co-payment from users.¹⁵

The hospital decides the health level, \bar{h} , where it discharges the patient. \bar{x}^H is the level of hospital services that gives the health level \bar{h} . It is reasonable that the hospital chooses \bar{h} so that $h^3 \leq \bar{h} \leq h^2$. When a patient is discharged from the hospital, the care institution can

¹² As the cross derivatives are set equal to zero, the utility functions can be specified as additive in the components.

¹³ Note that in the utility function of the hospital, the health of other patients is not taken into account. Thus, we assume that there is no trade-off in treatment between regular patients and patients in need of municipal services after discharge. However, bed-blocking affects the financial situation of the hospital.

¹⁴ Note that this set up allows for budget deficits.

¹⁵ Activity-based funding for hospitals is not explicitly taken into account. However, the unit cost can be thought of as the cost net of activity based payments.

choose to offer services or to let the patient stay longer at the hospital.¹⁶ However, if the care institution decides to let the patient be at the hospital instead of offering care services, it has to pay a fee, t , per extra services (for instance per day at the hospital), x_t^H , to the hospital. This fee is set exogenously by a Governmental decision maker. Thus, the care institution decides whether the patient should receive hospital- or care services if $h \geq \bar{h}$.

Based on this we can define the total hospital services given to one patient as

$$(5) \quad x^H = \bar{x}^H + x_t^H,$$

where \bar{x}^H follows from the hospitals choice of \bar{h} , and x_t^H is decided by the care institution.

In the empirical analysis below, \bar{x}^H is called *treatment period* and x_t^H is *bed-blocking*. It follows that

$$(6) \quad \bar{x}^H = \bar{x}^H(\bar{h}), \bar{x}_{\bar{h}}^{H'} > 0,$$

i.e., when the discharge health level of the patient increases, the hospital needs to increase its health services for the patient to reach this level. In the analyses below, we simplify and use \bar{x}^H as the decision variable for the hospital.

To study the optimal health services provided, the starting point is that a patient is in the hospital and the hospital needs to decide when to discharge her. The decision will obviously depend on the reactions of the care institution.

3. Solving the model

The model describes a Stackelberg game where the hospital is the leader and the care institution is the follower. However, the hospital predicts the reactions of the care institution for different levels of \bar{x}^H .

¹⁶ Note that if the hospital discharges the patient at health level h^2 , there are no health impacts of letting the patient stay at the hospital after discharge. The only reasons for this are financial incentives or capacity constraints at the care institution.

To solve the model, we therefore, start with the care institution. The care institution decides on its strategy for different levels of \bar{x}^H that are taken as given.

The decisions of the care institution

For any given level of t and \bar{x}^H , the institution wants to maximize

$$(7) \quad U^C = u^C \left(n \cdot h(x^H, x^C, \delta), B^C - p^C \cdot nx^C - t \cdot nx_t^H \right)$$

with respect to x^C and x_t^H , given equation (5).

Assume first that the care institution decides to offer care services, i.e., $x_t^H = 0$ and $x^C > 0$.

Then the first order condition is

$$(8) \quad \frac{\partial u^C}{\partial nh} h'_{x^C} = \frac{\partial u^C}{\partial m^C} p^C,$$

i.e., the marginal benefit in utility terms of better health should equal the costs defined as the marginal effect on utility of higher spending.

By differentiating (8), we find that the second order condition for maximizing utility is fulfilled, i.e., $A < 0$ (see Appendix 1).

If the care institution decides to let the patient stay longer at the hospital, i.e., $x_t^H > 0$ and $x^C = 0$, the first order condition is

$$(9) \quad \frac{\partial u^C}{\partial nh} h'_{x_t^H} = \frac{\partial u^C}{\partial m^C} t.$$

Again, the marginal effects on utility of a higher health level should equal the negative utility effects of higher costs due to paying the fee. Also in this case, the second order condition is fulfilled; $B < 0$ (see Appendix 1).

Let x^{C*} be the solution to equation (8) and x_t^{H*} the solution to equation (9). Whether the care institution chooses offering care services or to let the individual stay longer at the hospital depends on the value functions. If

$$(10) \quad u^C\left(n \cdot h(\bar{x}^H, x^{C*}, \delta), B^C - p^C \cdot nx^{C*}\right) > u^C\left(n \cdot h(\bar{x}^H + x_t^{H*}, 0, \delta), B^C - t \cdot nx_t^{H*}\right),$$

care services should be chosen. If the right hand side is larger, it is optimal to let the individual stay longer at the hospital.

How would the decisions of the care institution depend on the discharge level of health? This can be found by differentiating the first order conditions.

For $x_t^H = 0$ and $x^C > 0$, we find by using the second order condition ($A < 0$),

$$(11) \quad \frac{dx^C}{d\bar{x}^H} = -\frac{U_{nh, nh}^{C''} n \cdot h'_{x^H} h'_{x^C} + U_{nh}^{C'} \cdot h''_{x^C, x^H}}{A} < 0.$$

Thus, a higher level of services provided at the hospital before discharging the patient will reduce the level of care services provided by the care institution.

Further, for $x_t^H > 0$ and $x^C = 0$, we get by using the second order condition ($B < 0$),

$$(12) \quad \frac{dx_t^H}{d\bar{x}^H} = -\frac{U_{nh, nh}^{C''} n \cdot (h'_{x^H})^2 + U_{nh}^{C'} \cdot h''_{x^H, x^H}}{B} < 0.$$

This means that the extra time at hospital after discharge will go down if the discharge health level is higher. We further see from (12) and equation (28) in Appendix 1 (definition of B)

that $-1 < \frac{dx_t^H}{d\bar{x}^H} < 0$, i.e., we do not have full crowding out of hospital services after the

discharge date, and the total hospital services, $x^H = \bar{x}^H + x_t^H$, will actually be higher. The reason is that hospital services before and after the discharge date do not have symmetric

effects on the budget as only the latter has an impact on the spending of the care institution. This gives the following result:

Result 1: *When the hospital chooses a higher (lower) discharge health level, the services offered by the care institution as well as bed-blocking will decrease (increase).*

Can a higher discharge health level make the care institution change its decision whether to offer care services or to let the patient stay longer at the hospital? This depends on the effect on the value functions in equation (10). As seen from the left hand side of equation, i.e., when the care institution decides to offer services, a higher discharge health level will have a positive effect on the spending, but an ambiguous effect on health as hospital services will increase, but care services will go down. Thus, we cannot say if the value function for the care institution increases if it decides to offer care services. However, if the care institution decides to let the patient stay at the hospital, the value function will actually increase when the discharge health level increases, as both the health level and the financial situation of the care institution improves. Thus, we cannot in general tell how a change in the discharge time affects the care institutions decision whether to take the patient home or not. This can be summarized in the following corollary:

Corollary: *The care institution may decide to take the patient home after discharge when the discharge health level increase, or alternatively, decide to let the patient stay at the hospital after discharge if the discharge health level is reduced.*

The decision of the hospital

The hospital wants to maximize

$$(13) \quad U^H = u^H \left(n \cdot h(x^H, x^C, \delta), B^H - p^H \cdot nx^H + t \cdot nx_t^H \right)$$

with respect to \bar{x}^H , given equations (5) and the reactions of the care institution given by (11) and (12).

The first order condition is

$$(14) \quad \frac{\partial u^H}{\partial nh} \left(h'_{x^H} \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) + h'_{x^C} \frac{\partial x^C}{\partial \bar{x}^H} \right) = \frac{\partial u^H}{\partial m^H} \left(P^H \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) - t \frac{\partial x_t^H}{\partial \bar{x}^H} \right).$$

As for the care institution, the marginal benefit in utility terms of better health should equal the negative marginal effect on utility of higher spending. We know from (11) that when care services are offered, the health effects of offering more hospital services may be outweighed by reduced health effects of reduced care services, i.e., $\frac{dx^C}{d\bar{x}^H} < 0$. Then obviously the decision depends on the marginal health effects of the different types of services. Further, the costs of offering more hospital services increases with lower total fee payments when the care institution has decided to pay the fee, as we know from (12) that $-1 < \frac{dx_t^H}{d\bar{x}^H} < 0$. Note, however, that both effects will not happen simultaneously as we do not have $x^C > 0$ and $x_t^H > 0$ at the same time.

An increase in the fee

We now study how an increase in the fee, t , affects the decisions of the hospital and the care institution. Let us first start with the care institution.

Assume first that the higher fee does not change the decision to offer services, meaning that if for instance the care institution has decided to offer care services, the increase in the fee will not affect that decision. Thus, for $x_t^H = 0$ and $x^C > 0$, a change in the fee does not have any impact.¹⁷ We therefore study the case where $x_t^H > 0$ and $x^C = 0$.

Differentiating the first order condition (9) and inserting from (28) in Appendix 1 gives:

$$(15) \quad \frac{dx_t^H}{dt} = - \frac{U_{m^c, m^c}^{C''} n \cdot tx_t^H - U_{m^c}^{C'}}{B} < 0$$

We then have the following result:

Result 2: *An increase in the fee reduces bed-blocking, ceteris paribus.*

¹⁷ We return to this at the end of this subsection.

Let us now look at how the increase in the fee affects the discharge decision of the hospital.

To study this, we use the first order condition (14) when $x_t^H > 0$ and $x^C = 0$, i.e.,

$$(16) \quad \frac{\partial u^H}{\partial nh} h'_{x^H} \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) = \frac{\partial u^H}{\partial m^H} \left(p^H \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) - t \frac{\partial x_t^H}{\partial \bar{x}^H} \right).$$

The second order condition for an optimal solution is $C < 0$ (see Appendix 1).

Differentiating (16) and using the definition of C in Appendix 1 gives:¹⁸

$$(17) \quad \frac{d\bar{x}^H}{dt} = \frac{\frac{\partial x_t^H}{\partial t} \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) \left(U_{nh,nh}^H n \cdot (h'_{x^H})^2 + U_{nh}^H \cdot h'_{x^H, x^H} \right) + U_{m^H, m^H}^H n \cdot \left((p^H - t) \frac{\partial x_t^H}{\partial t} - x_t^H \right) \left(p^H \left(1 + \frac{\partial x_t^H}{\partial \bar{x}^H} \right) - t \frac{\partial x_t^H}{\partial \bar{x}^H} \right) + U_{m^H}^H \frac{\partial x_t^H}{\partial \bar{x}^H}}{C}$$

By studying the equation, we see that the effect on the discharge health level and therefore services is indeterminate. The reason for this is that an increase in the fee reduces the time at hospital after discharge, x_t^H , and will therefore have a negative impact on patient health.¹⁹

This goes in the direction of higher discharge health services, \bar{x}^H , to increase the hospital utility.²⁰ On the other hand, a higher fee means higher income to the hospital, but a higher fee also reduces the care institutions incentive to let the patient stay at the hospital after discharge, see (15). Both give an incentive for the hospital to reduce \bar{x}^H as this will increase services after discharge, see (12). Thus, in general, we cannot, therefore, tell how the hospital changes the health discharge level due to an increase in the fee. However, if the health effect of staying at the hospital after discharge, x_t^H , is small, i.e. if \bar{h} is close to h^2 (see Figure 1), the financial incentive will dominate for the hospital, and the result will be a lower discharge health level and health services. On the other hand, if the discharge time before the increase in

¹⁸ The decision of the hospital depends among other things on the characteristics of the reaction function of the care institution to the discharge health level, i.e., $\frac{\partial^2 x_t^H}{\partial \bar{x}^H \partial t}$. From equation (12), it can be seen that these reactions depend on third derivatives, which are hard to determine. Anyway, it is reasonable that these reactions are not very significant, i.e., $\frac{\partial^2 x_t^H}{\partial \bar{x}^H \partial t} \approx 0$. This is assumed in equation (17). The full equation is specified in Appendix 1.

¹⁹ Note that in this decision problem, the hospital does not take into account care services after the care institution has brought the patient home. It is concerned about the short term and the medium period before the patient moves back home.

²⁰ Note that we do not have full crowding out.

the fee was close to h^3 , the discharge date cannot be reduced. One interpretation of h^3 is that it is not medically advisable to discharge at a lower health level, and the hospital will not do that. However, the discharge time can possibly be increased if bed-blocking, x_i^H , is reduced and the health effect of this is large, outweighing the financial incentives.

This can be summarized as the following result:

Result 3: *An increase in the fee can increase as well as decrease the health discharge level. The outcome depends on the trade-off between better patient health and income. If the health effect of staying at the hospital after discharge is sufficiently small, the discharge health level will go down. On the other hand, if the discharge health level before the introduction of the fee was set at the minimum level, the discharge time will not go down.*

As we in general cannot tell how the hospital changes the health discharge level due to an increase in the fee, we cannot tell how an increase in the fee will affect the decision of the care institution on giving care services or to let the patient stay longer at the hospital. However, based on the discussion above and the Corollary, we may have some interesting conclusions. Even if the care institution decides to take the patient home earlier when a tax is introduced, in a game with several care institutions, more care institutions may decide to let the patient stay at the hospital after a tax is introduced if the health benefits of staying at the hospital are high enough. Thus we may end up in a situation with shorter stays at the hospital after discharge, but that more patients will stay at the hospital after discharge, even if these stays are short. We summarize this as follows:

Result 4: *We cannot rule out that the care institution may change its decision from giving care services to let the patients stay at the hospital after discharge when a fee is introduced.*

Changes in budgets

As mentioned in the introduction, the Coordination Reform also introduced an income transfer from hospitals to municipalities as more health and care services are meant to be produced in the municipalities. We introduce this in the model as a balanced budget change where the sum of the budgets of the hospital and the care institution is constant ($B^H + B^C = \bar{B}$). This gives

$$(18) \quad dB^C = -dB^H > 0 .$$

From the decision problem of the care institution, (7), we find that if the care institution decided to offer care services ($x_t^H = 0$ and $x^C > 0$), more municipal services are offered, i.e., the desired effect of the reform:

$$(19) \quad \frac{dx^C}{dB^C} = \frac{U_{m^c, m^c}^{C''} P^C}{A} > 0$$

However, if the care institution decides to let the patient stay at the hospital ($x_t^H > 0$ and $x^C = 0$), it will also demand more hospital services:

$$(20) \quad \frac{dx_t^H}{dB^C} = \frac{U_{m^c, m^c}^{C''} t}{B} > 0$$

Thus, the income effect leads to a higher production of services.

This gives the following result:

Result 5: *A higher budget leads to more bed-blocking if the care institution decides to let the patient stay at the hospital, ceteris paribus.*

Whether or not the care institution decides to take the patient home after the budget change depends again on the value functions. With a higher budget and the responses above, patients' health and the financial situation for the care institution will improve, and it is in general not possible to say how this decision will be affected.

How will this affect the hospital's decision on discharge? Let us study the case where $x_t^H > 0$ and $x^C = 0$, i.e., the care institution has decided to let the patient stay at the hospital after discharge. From the decision problem described above, (13), we find:²¹

²¹ For simplicity, we have set $\frac{\partial^2 x_t^H}{\partial \bar{x}^H \partial B^C} \approx 0$. The exact expression is in Appendix 1.

$$(21) \quad \frac{d\bar{x}^H}{dB^C} = - \frac{\left[\frac{\partial x_t^H}{\partial B^C} \left(1 + \frac{\partial x_t^H}{\partial \bar{x}} \right) \left(U_{nh,nh}^{H''} n(h_{x^H}^H)^2 + U_{nh}^{H''} h_{x^H,x^H}^{H''} \right) + U_{m^H,m^H}^{H''} \left(1 + n \frac{\partial x_t^H}{\partial B^C} (p^H - t) \right) \left(p^H \left(1 + \frac{\partial x_t^H}{\partial \bar{x}} \right) - t \frac{\partial x_t^H}{\partial \bar{x}} \right) \right]}{C}$$

Thus,

$$(22) \quad \frac{d\bar{x}^H}{dB^C} < 0 \quad \text{for } (p^H - t) \geq 0.$$

As long as the fee is not too high, the hospital will reduce the discharge time. Lower hospital budgets will reduce the production of services at the hospital. In addition the hospital knows that parts of this will be outweighed by larger demand for hospital services after discharge as long as the fee is not too large, thus the negative effect of patients' health will be partly reduced. If $(p^H - t) < 0$, the effect is not clear. The reason is that in this case, the hospital will have a positive net income from producing health services after discharge. As long as there is some substitution between services produced before and after discharge, the hospital may have an incentive to cut down the discharge health level. If, however, it is set at the minimum level, h^3 (see Figure 1), budget changes will have no effect on the discharge time.

This can be summarized as follows:

Result 6: *Lower hospital budgets and higher municipal budgets will reduce the discharge health level at the hospital as long as it is not set at the minimum level.*

Summarizing the analytical results²²

The main results of the analysis can be summarized as follows. The budget change and the change in the fee give incentives in different directions for the care institution. A higher fee gives an incentive to reduce time at hospital after discharge (Result 2), while a higher budget gives incentives to let the patient stay at the hospital (Result 5). However, the effect on bed-blocking also depends on how the hospital changes the discharge time. We find that a higher fee has indeterminate effects on the discharge time as this depends on the hospital's trade-off

²² We have also made some calculations on how different patient needs, illustrated by δ , affect the decisions. This may illustrate the effects for different diagnosis, and is available from the authors on request.

between patient health and income. If the health effect of staying at the hospital after discharge is sufficiently small, the discharge time will go down (Result 3). This result is also supported by a lower hospital budget (Results 6). A lower discharge time will partly be outweighed by more bed-blocking if there are positive health effects for the patient to stay at the hospital (Result 1). Thus, the effect on bed-blocking is in general indeterminate as the different incentives go in different directions.

To better understand the intuition, consider again the case where the discharge health level is originally set close to h^2 in Figure 1. In this case, changing the discharge date will have minimal impacts on health at discharge. Thus, a higher fee will reduce the discharge date. As, the health effects of bed-blocking will also be small in this case, the decision of the care institution will mainly be driven by the financial incentives, and whether bed-blocking will decrease or not will depend on the relative sizes of the negative substitution effect (the increased price on bed-blocking – the fee) and the positive income effect (higher budgets).

In the case where the hospital discharges patients at the minimum possible health level, h^3 , the tax will not give a lower discharge time. In all intermediate cases, where the discharge date is set between h^3 and h^2 , both health effects and financial incentives affect the decisions, and the decisions depend on how the institutions weigh the effects.

Whether the reform changes the behaviour of the care institution so that it changes its decision to let the patient stay at the hospital after discharge or not, is not possible to predict based on general utility functions. However, we cannot rule out that more care institutions decide to let the patient stay at the hospital after discharge as a result of the reform (Results 4). One illustration of this is if the discharge time goes down and the care institution values the health effect of additional time at the hospital to be sufficiently large.

4. Empirical analysis

Data

The data on the number of bed-blocking days for 2008 to 2014 in Norwegian hospitals was obtained from the Norwegian Patient Registry. This is a comprehensive national registry with information on every admission to all Norwegian hospitals, and altogether the data contains 5.6 million inpatient hospitalizations. The information for each hospital event includes the date for when the patient arrived at the hospital, the diagnosis the patient was given, age, gender, when the hospital considered the patient ready to be discharged, and the date when they were in fact discharged. All patients had a discharge date, but only patients believed to be in need of municipal services were recorded with a separate “ready to be discharge date.” Most patients do not require municipal services, and of the 5.6 million events, 5.2% were recorded with a ready to be discharged date (294 965 events). Descriptive statistics for the sample is provided in Table 1.

Table 1: Descriptive statistics of data used in the analysis

	Regular patients		Patients discharged to municipal care	
	<u>Reform</u>			
	Before	After	Before	After
Number of observations	3 069 649	2 232 917	102 130	190 997
Average age (years)	49	48	77	78
Male (%)	46	46	41	42
Avg. length of stay (days)	4.6	4.1	14.2	7.8

The total number of number of bed blocking days due to the inability of municipalities to accept patients who were ready to be discharged, was reduced by 58% from 2011 to 2012 and it remained significantly lower in all the post-reform years compared to the pre-reform period. (Figure 2). At the same time as the total number of days decreased, the hospitals increased the number of patients reported to be ready to be discharged to the municipalities by 94% from 2011 to 2012, and it continued to increase in the years thereafter (Figure 3).

Figure 4 shows the average length of a hospital stay decomposed into treatment days and bed-blocking days. Average treatment days for each inpatient hospital event also have a downward trend for all the years.

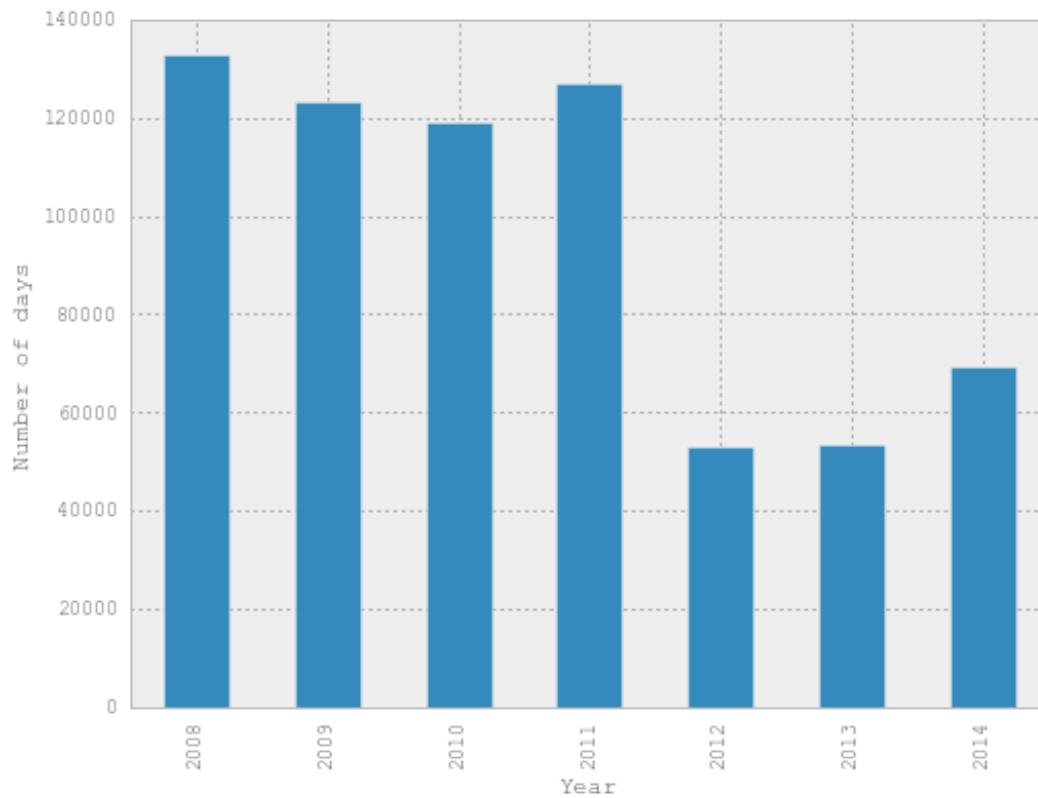


Figure 2: Annual number of bed-blocking days in Norwegian Hospitals

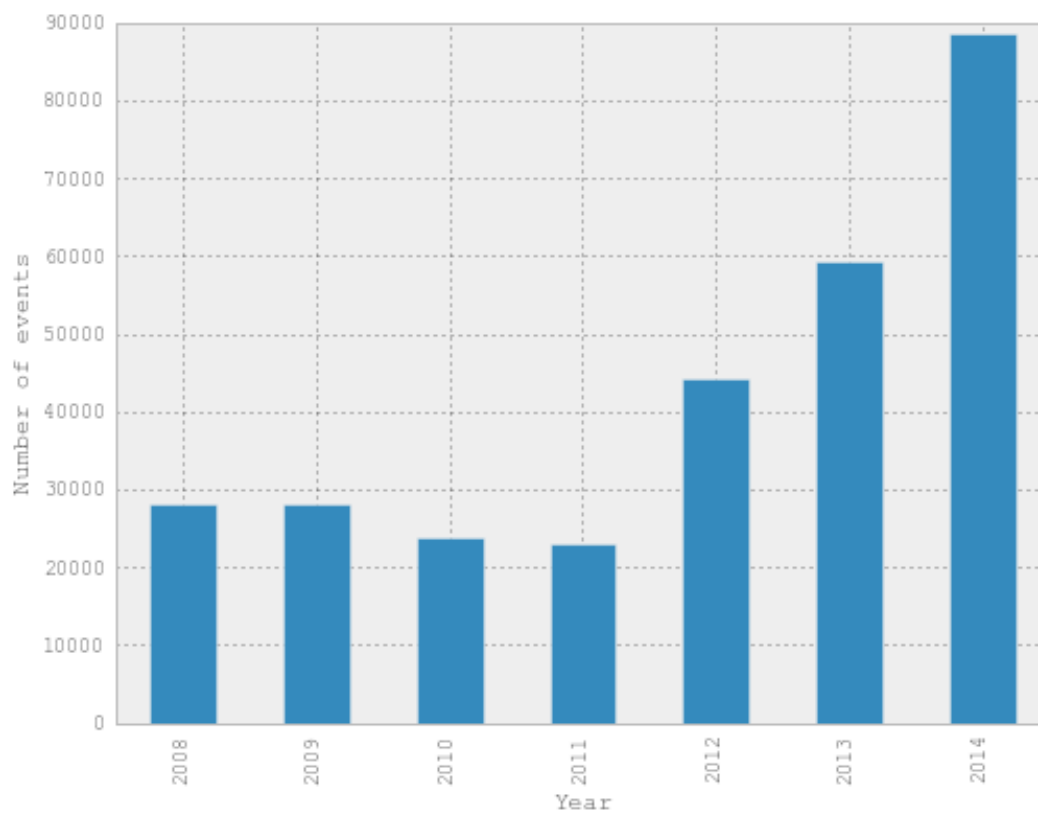


Figure 3: Number of patients the hospitals reported to be ready to be discharged to the municipalities

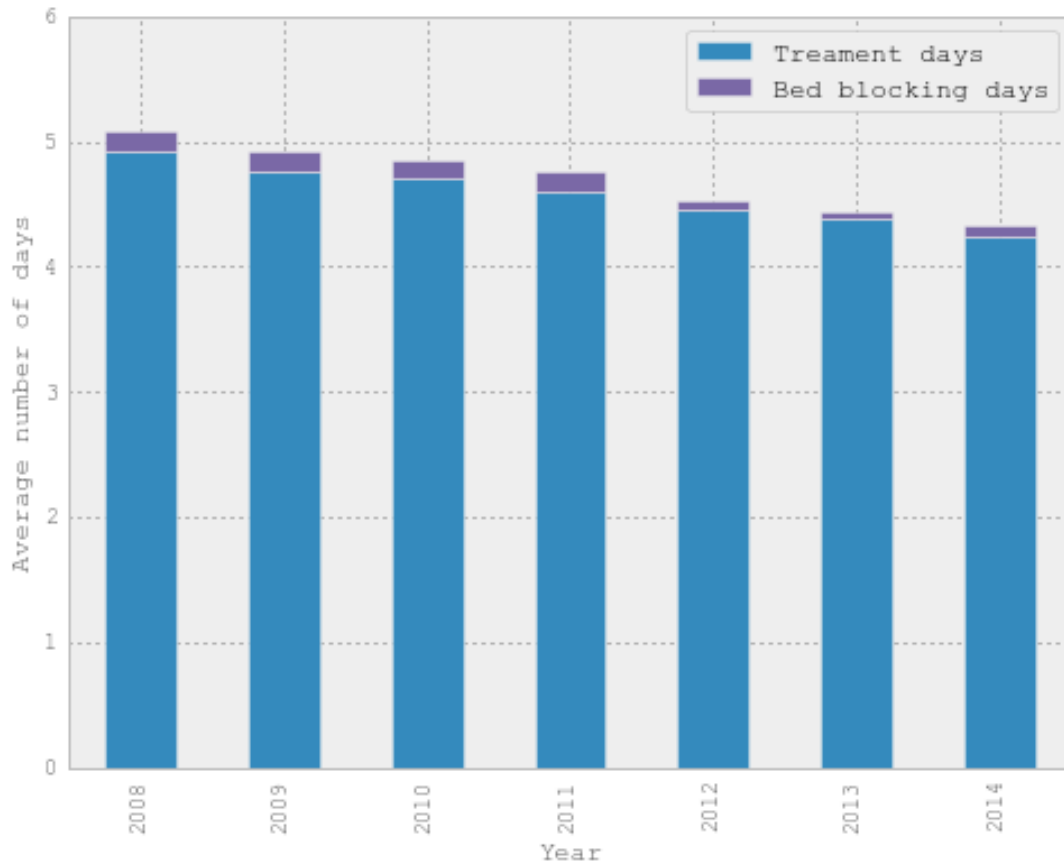


Figure 4: Average length of hospital stays separated into treatment days and bed-blocking days

The distribution of the number of hospital events with one or more bed-blocking days in the year previous to the reform (2011) and in the year after (2012) shows a clear change in the distribution. In the year after the reform there was a distinct drop in the number of events with 4 or more bed-blocking days, the number of events with 2 or 3 stayed about the same, while the number of events with one bed blocking days increased greatly. The increase in the number of events with one day bed-blocking may be due to two reasons. First, reducing bed-blocking days does not mean that they are reduced to zero, and multiple days of bed-blocking can have been reduced to one day as a consequence of the reform. Second, we cannot rule out that some care institutions change their decisions and let some patients stay at the hospital as a consequence of the reform, as shown in the theoretical model (see Result 4 above). The reason may be that health consequences of reduced hospital stays are considered serious by the care institutions.

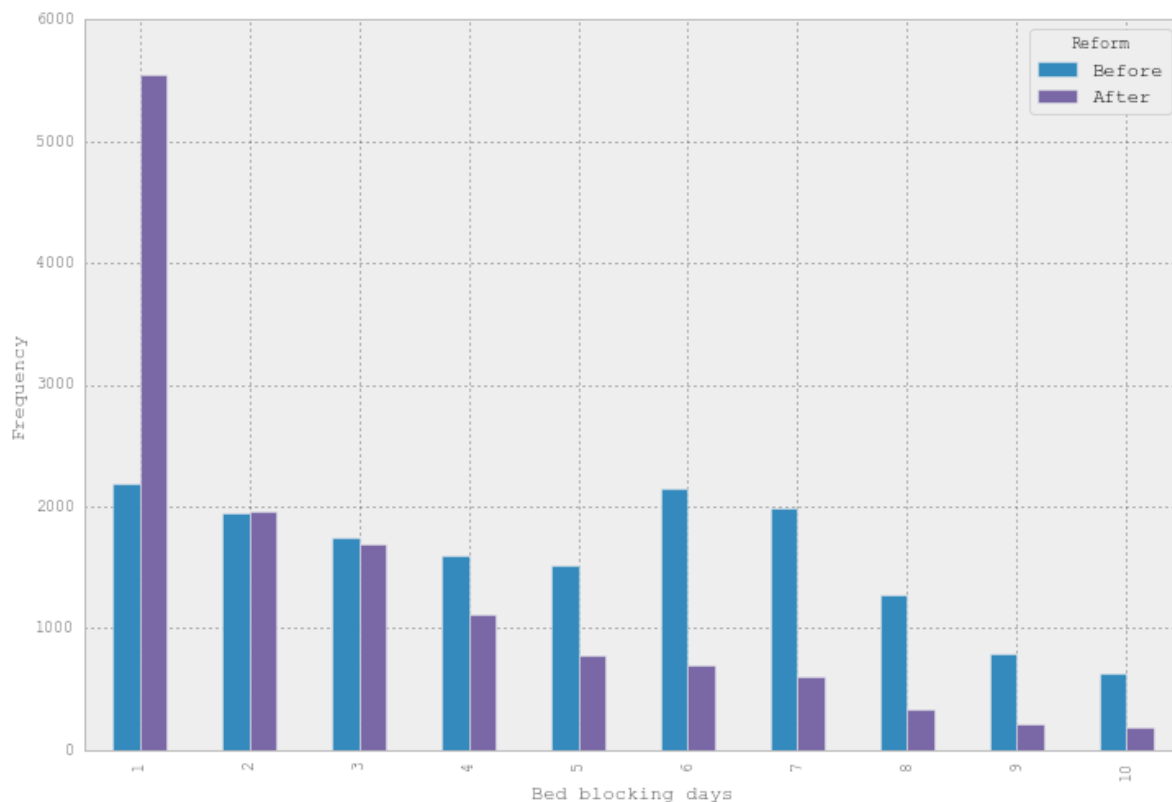


Figure 5: Frequency of bed-blocking days of different lengths before (2011) and after the reform (2012)

Method

Estimating the effect of the reform on the number of bed-blocking days presents several methodological problems. A simple before-and-after comparison of average length of stay among patients who receive municipal care, shows a 45% decrease (from 14.2 days to 7.8 days on average, see Table 1) and the total number of bed blocking days went down by 58% between 2011 and 2012 (from 128 157 to 53 581 days, see Figure 2). However, the directly observed reduction before and after the reform is not a good measure of the causal effect because the reform may have led hospitals to alter their policies on how many patients to record in need of municipal services and how early they are considered ready to be discharged. The theoretical model demonstrated how the fee changed the incentives not only for the municipalities, but also the hospitals. This is important for the estimation of the causal effect of the reform since if the hospitals started recording more patients as ready to be discharged, and earlier, the true effect of the reform is larger than a naive before and after comparison of total number of bed-blocking days indicates.

In order to estimate whether and how much the hospitals changed their practice in response to the reform, we need an approach that estimates the counterfactual: How would the hospital have behaved if the incentives had not changed? The data contains information about the total length of stay for each patient, but instead of the total length of stay, we will focus on the number of treatment days in hospital, \bar{x}^H , which is defined as the number of days in hospital before the patient is reported as ready to be discharged (for patients discharged to municipal care) and the actual discharge date for regular patients who are not reported to need municipality care.

A reduction in the mean number of treatment days before and after the reform is not enough to prove that the hospitals have changed behaviour in response to the reform. First of all, there may be a long term trend towards shorter treatments. Second, confounding factors such as the effects of the other parts of the reform implemented at the same time (such as municipal co-funding, see the introduction), could change the composition of patients towards diseases or age groups that affect the mean days in treatment. In order to solve these problems, we estimate a model which predicts how the mean treatment time should have developed in the absence of a reform after adjusting for time trends and compositional changes in the patient group. This model will be used to predict the mean number of treatment days one would expect without the fee.

To model the length of the treatment period²³ we use a Poisson regression model since days in hospitals is a count variable that is skewed with some treatments lasting a long time, but with most treatments lasting only a few days (for more on the Poisson model, see Jones et al., 2013). In order to estimate the reporting practice before the reform, the model was fitted using data on every admission episode before the reform ($t < 2012$) with gender, age, age squared and the main diagnostic category of the individual as well as a general time trend (to capture trends in average treatment days over time) as independent variables:

(23)

$$y_{i,t} = f(\alpha + \beta_1 male + \beta_2 age + \beta_3 age_squared + \beta_4 diagnosis + \beta_5 year)$$

²³ For simplicity, in the equations below, we use $y_{i,t}$ as the number of treatment days. Note that this is the same as \bar{x}^H in the theoretical model.²

The model predicts the number of days in treatment (i.e., before being discharged or reported as ready to be discharged) for a patient with a given gender, age, and main diagnosis. Since we only used data on individuals admitted before the reform to estimate the coefficients, the model represents the practice used by the hospitals before the reform. The results from the regression can then be used to predict the number of days in treatment one would observe for every admission after the reform if the hospitals simply continued with the same reporting practice after the reform, i.e., $\hat{y}_{i,t>2012}$:

(24)

$$\hat{y}_{i,t>2012} = f(\alpha + \beta_1 male + \beta_2 age + \beta_3 age_squared + \beta_4 diagnosis + \beta_5 year)$$

In the next step, we examine the difference between the observed and predicted number of days in treatment. Given a patient with the same gender, age, main diagnosis, and after adjusting for time trends, the predicted number of days in treatment should be the same both before and after the reform for patients with the same characteristics if the hospitals do not change their behaviour. To examine whether this is the case, we calculate the difference ($\Delta_{i,t}$) between the observed and predicted number of days in treatment for every individual admitted after the reform:

$$(25) \Delta_{i,t} = y_{i,t} - \hat{y}_{i,t}$$

Then, to find overall changes in treatment days over time, we aggregate the individual differences from equation (25) and calculate the average deviation between the observed and predicted in treatment across all individuals in each year:

(26)

$$\bar{\Delta}_t = \frac{\sum_{i=1}^n \Delta_{i,t}}{n} = \frac{\sum_{i=1}^n (y_{i,t} - \hat{y}_{i,t})}{n}$$

If the difference between the observed and predicted treatment days diverges significantly after the introduction of the reform, it indicates that the hospitals have adapted strategically by changing the average number of treatment days, i.e., reporting more patients as ready to be

discharged earlier than they did before the reform. The size of the difference is used to estimate to what extent the reform induced strategic adaptation.

This method is a conservative test of effects in the sense that one would not expect the overall average treatment period to change much since the number of patients affected by the reform (those who need municipal services) is small relative to the number of patients who are not in need of municipal services. As shown by Table 1, only 3.3% of the hospital events before the reform involved patients who were reported to be in need of municipal services in order to be discharged.

Results

Appendix 2 shows the result from the Poisson regression estimating the expected number of treatment days given a patients age, gender, diagnosis and year of admission using all treatment episodes before the reform. Figure 6 shows the difference between the predicted treatment days from the regression and the actual average number of treatment days in the different years. In the pre-reform period, the difference between the predicted and the observed number of treatment days was close to zero, while in the post-reform period, the observed average days in treatment were 1.8% lower than the predicted average treatment days for a hospital stay (an average difference of 0.08 days for every event). Finally, Figure 7 shows the predicted and observed number of treatment days before and after the reform for the group that the reform was expected to affect, i.e., the patients whom the hospital reported to be in need of municipal services in order to be discharged. On average for the years 2012-14, the number of treatment days in this group was reduced by 21.9% (1.5 days) as a result of the reform.

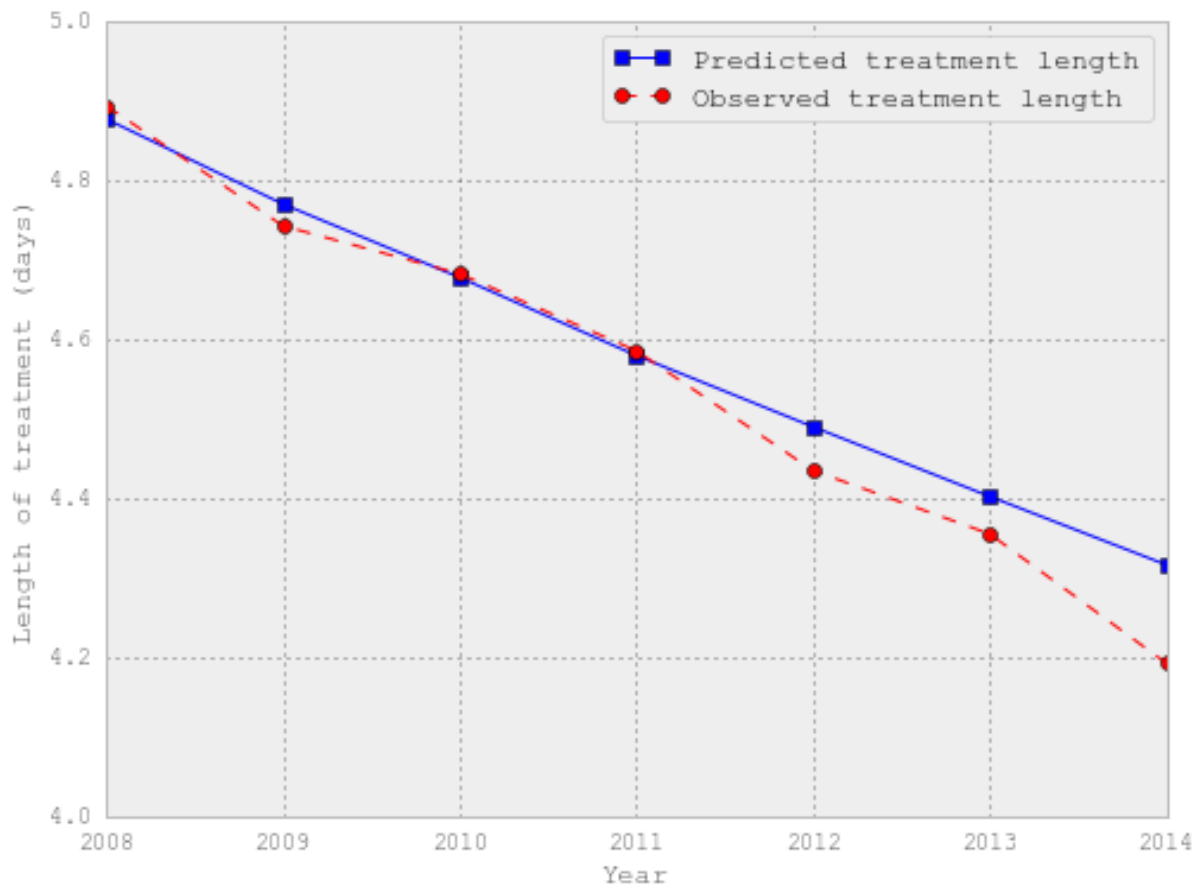


Figure 6: Actual and expected average number of treatment days for an inpatient hospital stay in different years (Expected number of days is based on the regressions model estimated on all pre-reform treatment episodes).

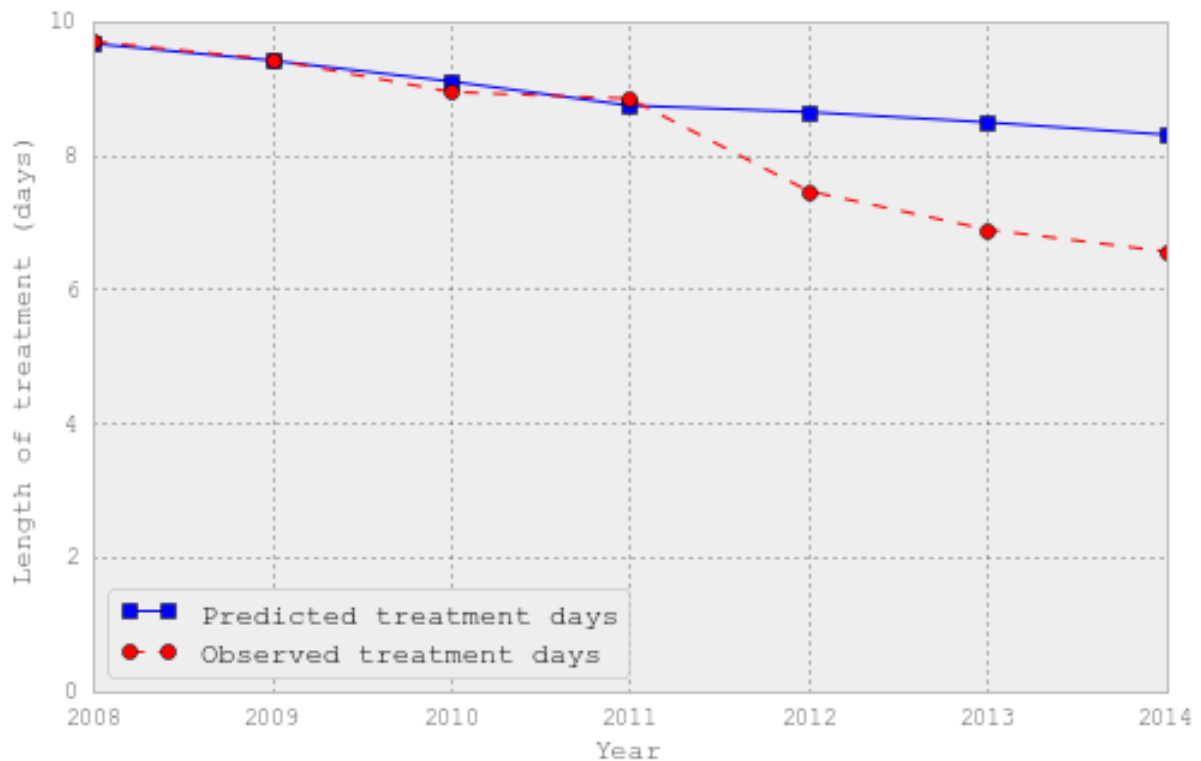


Figure 7: Predicted and observed average number of treatment days for the sub-group of patients who were reported to be in need of municipal services before they could be discharged.

Discussion

The data show that the introduction of the fee significantly reduced the number of bed-blocking days in hospitals. Moreover, the results also show that the hospitals adapted to the reform by reporting more patients as ready to be discharged than before and by reducing the number of treatment days. Based on the expected number of treatment days for patients with a given gender, age and diagnosis before the reform, the average length of treatment was reduced by 0.1 days. This is only an average and since most patients were not affected since they did not need municipal services, the reduction among those affected was larger than 0.1 days, namely 1.8 days on average. For instance, patients with femur fracture who were older than 60 years old, had a reduction in the number of treatment days (i.e., before being reported to be ready to be discharged) by an average of 2.1 days after the reform. In the analytical model, we found that the results on treatment time is indeterminate as it is a result of incentives going in different direction. As the treatment time goes down, on interpretation may be that the financial incentives count more than the health incentives, or that the health effects of bed-blocking are insignificant. In the latter case, the discharge health level would be

close to h^2 in Figure 1. In this case, it is optimal for the hospital to reduce the discharge time as outlined above. Financial incentives will dominate for the care institution, and it will be optimal to reduce bed-blocking if the effect of the increase in the fee (substitution effect) is higher than the effect of larger budgets (income effect). If the initial discharge level is close to h^2 , a reduction in treatment time and bed-blocking will not have large health effects. Some indicators of these health effects are readmission to hospital, mortality in hospitals and 30 day mortality after discharge. These effects of the Coordination Reform on readmissions are studied in Hagen et al. (2016). They do not find significant increases in readmission or mortality, which supports our hypothesis that the discharge health level was close to h^2 before the reform.

In the year after the reform, the total number of bed-blocking days was reduced from 128 000 to 53 000 days. This reduction is the net effect of two changes: First, the direct and intended effect which is that the municipalities increased their efforts to accept patients who were ready to be discharged. Second, the strategic and maybe unintended effect that hospitals started to report more patients ready to be discharged earlier than they had done previously.

To quantify the size of the different effects, one might estimate what had happened to the total number of bed blocking days if the hospital had not reduced their treatment period. The results indicate that in response to the reform, the hospitals reduced the average number of days in treatment (i.e., before the patient was discharged or ready to be discharged) by 0.1 days. If they had continued the old policy, these days would have been classified as treatment days and not bed blocking days. Multiplied by the total number of inpatient hospital stays, the change in reporting practice amounts to adding a total of about 50 000 days to the bed blocking statistics.²⁴ To interpret the size of this number it is useful to recall that previous to the reform the number of bed-blocking days in the year before the reform was close to 130 000. This means that the reform led to an almost 40% increase in bed blocking days as reported by the hospital, but the observed number fell because the fee also led the municipalities to greatly intensify their efforts to accept patients earlier.

Although the reform clearly underlines the power of financial incentives to promote integrated care, the result does not imply that money is the only useful tool. For instance,

²⁴ This is of course a simplification as we know from equation (12) that all reduction in treatment days will not be replaced by bed blocking.

previous studies have shown that organizational features, such as having a dedicated personnel and an office to promote speedy transfer from hospital to municipality care, also had a large effect on the number of bed blocking days in a hospital (Holmås et al., 2010). Other studies have found much weaker effects. For instance, a study of the experience with fees to reduce bed blocking in England, showed no significant effects (McCoy et al, 2007). However, the English fee was far lower than the Norwegian fee and the study also indicated that most English hospitals did not enforce the new system. In Norway the fee was implemented in an organised system of financial transfers and all municipalities and hospitals participated.

5. Conclusions

This paper studies the effect on bed-blocking of the Coordination Reform that was introduced in Norway in 2012. To reduce bed-blocking, a fee was introduced (NOK 4000) so that the municipalities have to pay the hospitals for patients who are ready to be discharged to municipal care services, but unable to leave because the municipalities do not provide the necessary services. To be eligible to receive the fee, the hospitals have to notify the municipalities in advance of patients who need municipal services. In this case, the fee applies from the first day the patient is considered ready to be discharged. The reform also induced a budget change with higher budget transfers to municipalities and lower budgets in hospitals, as more patients were expected to receive care services in the municipalities.

The methodological starting point for this analysis is a game between a hospital and a municipality where the hospital decides on the discharge date (treatment period) and the municipality responds by deciding how long the patient should stay at the hospital after discharge (bed-blocking), when it has to pay a fee to the hospital for bed-blocking. The Stackelberg game shows that a fee gives an incentive to reduce bed-blocking, while a higher budget gives an incentive to let the patient stay at the hospital. However, the effect on bed-blocking also depends on how the hospital changes the discharge time. A shorter treatment period will, *ceteris paribus*, induce more bed-blocking as long as this has a positive health effect for the patient. We find that a higher fee has indeterminate effects on the treatment time as this depends on the hospital's trade-off between patient health and income, and what the practise has been before the reform. If for instance the health effect of staying at the hospital

is sufficiently small, the discharge time will go down. This is the case if the discharge health level is in the upper part of the interval of what can be expected (Figure 1).

To study these incentives, we use data for bed-blocking from the Norwegian Patient Registry for the years 2008-14. The effect of the reform on bed-blocking was significant. The net effect is that bed-blocking is reduced from 128 000 to 53 000 days, i.e., 58%. However, the hospitals changed their practise by reducing the treatment period as well as increasing the number of patients reported ready for discharge. This means that the effect of the fee is rather strong. The increase in municipal activity was almost the double of what is indicated by the net effect because of the shorter treatment period. One interpretation of the results may be that the financial incentives count more than the health incentives, or that the health effects of bed-blocking are insignificant. As indicated above, the empirical results is in line with a practice where the hospitals had a relatively high discharge health level before the reform, and that a reduction in treatment time and bed-blocking would have relatively small health effects. The latter is confirmed by readmission data and data for mortality (Hagen et al., 2016).

Finally, this study illustrates the importance of considering strategic adaptation when predicting and evaluating policy reforms. The decisions will depend on how the different institutions weigh the different effects of the reform, and also on their practice before the reform.

Appendix 1: Second order conditions, the effect of tax increases, and balanced budget change

Second order conditions

The second order condition for the maximization problem described by equation (7) $\square x_t^H \square x^C$ fulfilled: fulfilled:

$$(27) \quad U_{nh,nh}^C n \cdot (h'_{x^C})^2 + U_{nh}^C \cdot h''_{x^C,x^C} + U_{m^C,m^C}^C n \cdot (p^C)^2 \equiv A < 0$$

If $x_t^H > 0$ and $x^C = 0$, the second order condition is also fulfilled:

$$(28) \quad U_{nh,nh}^C n \cdot (h'_{x^H})^2 + U_{nh}^C \cdot h''_{x^H,x^H} + U_{m^C,m^C}^C \cdot nt^2 \equiv B < 0$$

The second order condition for the maximization problem described by equation (13) $\square x_t^H \square x^C$ \square^{25}

$$(29) \quad \left(1 + \frac{\partial x_t^H}{\partial x^H}\right)^2 \cdot \left(U_{nh,nh}^H n \cdot (h'_{x^H})^2 + U_{nh}^H \cdot h''_{x^H,x^H}\right) + U_{nh}^H \cdot h'_{x^H} \frac{\partial^2 x_t^H}{\partial x^H \partial t} + U_{m^H,m^H}^H n \cdot \left(p^H \left(1 + \frac{\partial x_t^H}{\partial x^H}\right) - t \frac{\partial x_t^H}{\partial x^H}\right)^2 - U_{m^H}^H (p^H - t) \frac{\partial^2 x_t^H}{\partial x^H \partial t} \equiv C < 0$$

The effect of a tax increase for the discharge time

$$(30) \quad \frac{dx_t^H}{dt} = \frac{\frac{\partial x_t^H}{\partial t} \left(1 + \frac{\partial x_t^H}{\partial x^H}\right) \left(U_{nh,nh}^H n \cdot (h'_{x^H})^2 + U_{nh}^H \cdot h''_{x^H,x^H}\right) + U_{nh}^H \cdot h'_{x^H} \frac{\partial^2 x_t^H}{\partial x^H \partial t} + U_{m^H,m^H}^H n \cdot \left((p^H - t) \frac{\partial x_t^H}{\partial t} - x_t^H\right) \left(p^H \left(1 + \frac{\partial x_t^H}{\partial x^H}\right) - t \frac{\partial x_t^H}{\partial x^H}\right) - U_{m^H}^H \cdot \left((p^H - t) \frac{\partial^2 x_t^H}{\partial x^H \partial t} - \frac{\partial x_t^H}{\partial x^H}\right)}{C}$$

The effect of a balanced budget change for the discharge time

$$(31) \quad \frac{dx_t^H}{dB^C} = - \frac{\left[\frac{\partial x_t^H}{\partial B^C} \left(1 + \frac{\partial x_t^H}{\partial x^H}\right) \left(U_{nh,nh}^H n \cdot (h'_{x^H})^2 + U_{nh}^H \cdot h''_{x^H,x^H}\right) + U_{nh}^H \cdot h'_{x^H} \frac{\partial^2 x_t^H}{\partial x^H \partial B^C} + U_{m^H,m^H}^H n \cdot \left(1 + n \frac{\partial x_t^H}{\partial B^C} (p^H - t)\right) \left(p^H \left(1 + \frac{\partial x_t^H}{\partial x^H}\right) - t \frac{\partial x_t^H}{\partial x^H}\right) - U_{m^H}^H (p^H - t) \frac{\partial^2 x_t^H}{\partial x^H \partial B^C}\right]}{C}$$

²⁵ Note that the last term is not signed as we do not know $\frac{\partial^2 x_t^H}{\partial x^H \partial t}$. However, we know that C has to be negative to find an optimal solution.

Appendix 2: Summary of the Poisson regression

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=====
Dep. Variable:      Days in treatment  No. Observations:      3171779
Model:              Poisson           Df Residuals:          3171753
Method:             MLE               Df Model:              25
Date:              Wed, 06 Jan 2016    Pseudo R-squ.:        0.08171
Time:              18:51:53           Log-Likelihood:       -1.1749e+07
converged:         True               LL-Null:               -1.2795e+07
                                      LLR p-value:           0.000
=====

              coef      std err          z      P>|z|      [95.0% Conf. Int.]
-----
constant      40.7879      0.464      87.847      0.000      39.878      41.698
male           0.0510      0.001      92.597      0.000      0.050      0.052
ae             0.0122     5.11e-05     238.714      0.000      0.012      0.012
age_squared   -3.299e-05    4.77e-07    -69.117      0.000     -3.39e-05  -3.21e-05
year          -0.0198      0.000     -85.585      0.000     -0.020     -0.019
hdgDum_2      -0.4143      0.003    -118.422      0.000     -0.421     -0.407
hdgDum_3      -0.6733      0.002   -333.655      0.000     -0.677     -0.669
hdgDum_4       0.1712      0.001    145.554      0.000      0.169      0.174
hdgDum_5      -0.4146      0.001   -344.845      0.000     -0.417     -0.412
hdgDum_6      -0.1374      0.001   -109.747      0.000     -0.140     -0.135
hdgDum_7       0.0642      0.002     36.380      0.000      0.061      0.068
hdgDum_8      -0.0465      0.001    -40.549      0.000     -0.049     -0.044
hdgDum_9      -0.0879      0.002    -45.363      0.000     -0.092     -0.084
hdgDum_10     -0.2229      0.002   -101.044      0.000     -0.227     -0.219
hdgDum_11     -0.2016      0.002   -132.305      0.000     -0.205     -0.199
hdgDum_12     -0.3525      0.002   -141.062      0.000     -0.357     -0.348
hdgDum_13     -0.3115      0.002   -138.646      0.000     -0.316     -0.307
hdgDum_14     -0.1442      0.001   -100.441      0.000     -0.147     -0.141
hdgDum_15      0.3132      0.002    172.158      0.000      0.310      0.317
hdgDum_16     -0.3283      0.003   -104.537      0.000     -0.334     -0.322
hdgDum_17      0.1571      0.002     83.082      0.000      0.153      0.161
hdgDum_18      0.3861      0.002    228.691      0.000      0.383      0.389
hdgDum_19     -0.4283      0.003   -150.632      0.000     -0.434     -0.423
hdgDum_21     -0.3998      0.003   -153.015      0.000     -0.405     -0.395
hdgDum_23      0.8379      0.001    641.240      0.000      0.835      0.840
hdgDum_30     -0.2869      0.003    -84.831      0.000     -0.294     -0.280
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