Online Appendix for the paper "Information Integration, Coordination Failures, and Quality of Prescribing"

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I. ATC and ICD-10 Codes

Warfarin and NSAID ATC codes used in the data.

- Warfarin: B01AA03
- NSAID: M01AB01, M01AB02, M01AB05, M01AB08, M01AB51, M01AB55, M01AC01, M01AC02, M01AC06, M01AE01, M01AE02, M01AE03, M01AE11, M01AE52, M01AG01, M01AG02, M01AH01, M01AH05, M01AX01

ICD-10 codes used for gastrointestinal hemorrhage diagnosis in the data.

- K920, K921, K922, I850, K221, K250, K252, K254, K256, K260, K262, K264, K266, K270, K272, K274, K276, K280, K282, K284, K286, K290, K625

II. Reform Exogeneity

The key identifying assumption of our empirical approach is that the timing of technology adoption across municipalities is unrelated to the trends in our outcomes. To provide formal support for this assumption, we report the correlations between various municipality-level covariates from the pre-adoption years and the timing of the adoption of e-prescribing (Table A1). Specifically, the outcome is the log difference between the municipality's adoption date and the first adoption date, calculated in days. The municipality of Turku was the first municipality to adopt e-prescribing on May 20, 2010. Supporting our assumption, Table A1 shows no evidence for correlation between the covariates and the timing of the adoption.

To further test the exogeneity assumption, we follow Bhuller, Mogstad, and Salvanes (2017) and estimate the following model:

$$T_{mt} = (\Gamma_t \times X_{m,2009})'\Psi + \gamma_t + \nu_{mt}, \tag{4}$$

where Γ is a vector of biannual-level time dummies, X is a vector of municipality-level covariates from 2009, γ is time fixed effects, ν is an error term, and the outcome T_{mt} is a dummy variable equal to one if municipality m adopted e-prescribing in 6-month period t. For simplicity, we standardize the municipality-level covariates by dividing them by the corresponding standard deviations. Figure A1 plots the coefficients and the 95 percent confidence intervals from Ψ. As expected, the coefficients do not reveal any systematic correlation between the timing of the adoption and the covariates, further supporting the conclusion that technology adoption is not systematically related to differences in municipality characteristics.

Table A1

Correlation Between the Timing of Adoption of E-prescribing and Municipality-Level Covariates

	Covariate year		
	2008	2009	2010
Log(population)	−0.093	−0.088	−0.089
	(0.091)	(0.088)	(0.091)
Log(primary care costs)	0.126	0.141	0.091
	(0.115)	(0.140)	(0.086)
Percentage over 65 years	−0.009	−0.007	−0.006
	(0.013)	(0.011)	(0.010)
Percentage 15–64 years	−0.019	−0.016	−0.018
	(0.021)	(0.018)	(0.019)
Drug reimbursement index	0.008	0.006	0.006
	(0.007)	(0.006)	(0.007)
Morbidity index	−0.007	−0.006	−0.006
	(0.006)	(0.006)	(0.006)
Mortality index	−0.0004	0.001	0.001
	(0.001)	(0.001)	(0.001)
Log(outpatient visits in psychiatry)	−0.008	−0.013	−0.006
	(0.016)	(0.022)	(0.013)
Log(psychiatric inpatient periods of care)	0.086	0.015	0.013
	(0.074)	(0.027)	(0.026)
Semi-urban municipality	0.044	0.038	0.036
	(0.040)	(0.038)	(0.037)
Rural municipality	−0.056	−0.064	−0.069
	(0.087)	(0.096)	(0.098)
F statistic	31.24	35.983	35.983
Adjusted R^2	0.295	0.290	0.287
Observations	299	298	298
Hospital district FE	Yes	Yes	Yes

Notes: Each column shows parameter estimates from a separate regression using municipality-level data. The municipality covariates are from 2008, 2009, and 2010, in Columns 1, 2, and 3, respectively. The outcome in each regression is the log of the difference in the time of adoption of e-prescribing by the municipality relative to the earliest adoption time, calculated in days. The reference category for semi-urban and rural municipality indicators is urban municipalities. The variables are from the National Institute of Health and Welfare and from Statistics Finland. In each year, we exclude a few municipalities with missing observations in the covariates. Standard errors are clustered at the municipality level.

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

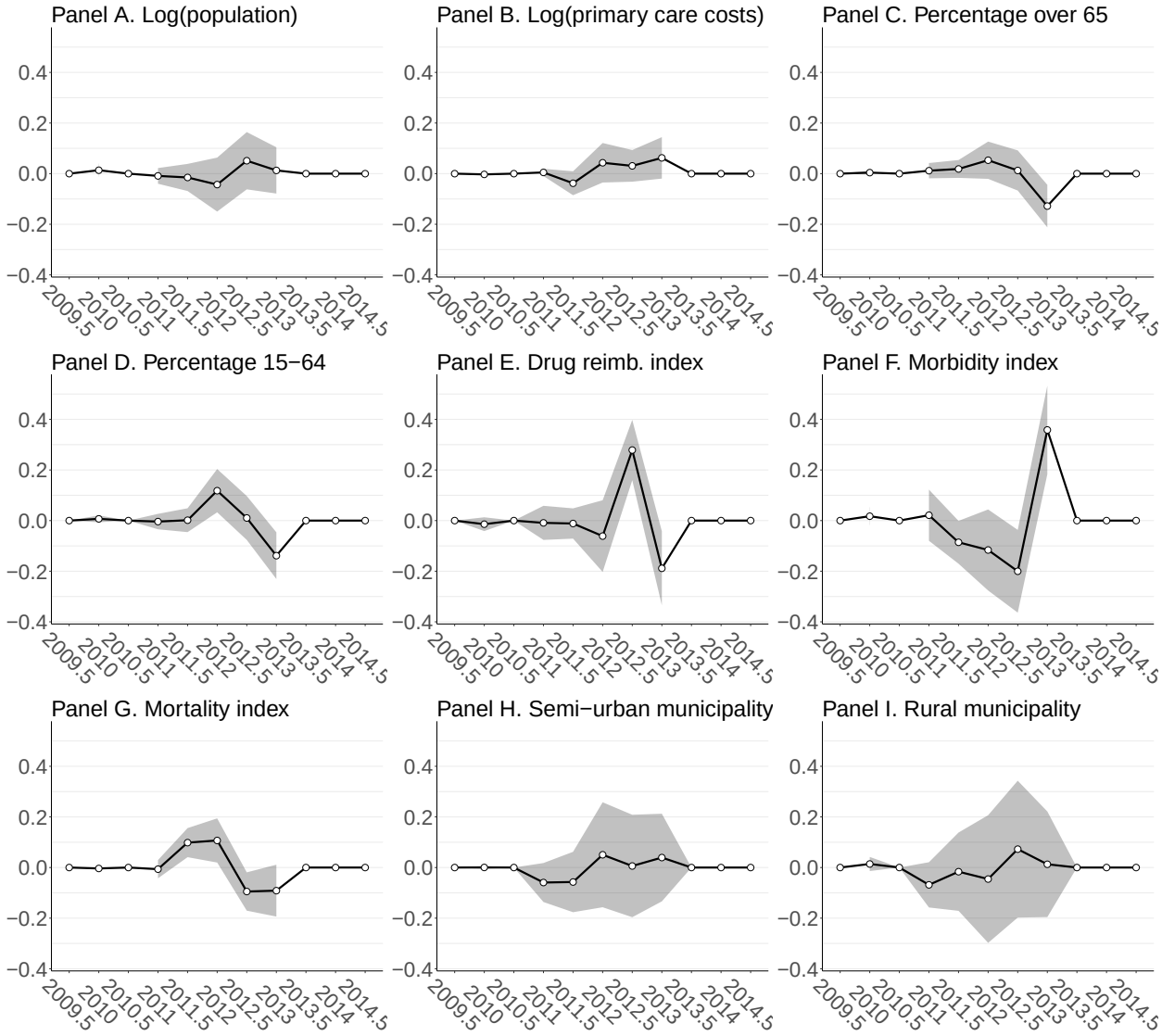

Figure A1

Adoption of E-Prescribing by Baseline Municipality Characteristics

Notes: Each panel plots coefficient estimates from a separate regression for interaction terms between a specific municipality covariate for 2009 and biannual dummies for the time of adoption of e-prescribing by the municipality. The regressions are estimated using municipality-level data. The outcome is a dummy variable that equals one when the municipality adopted e-prescribing during the particular 6-month period. The coefficient estimates are standardized by dividing the covariates by their corresponding standard deviations. See Table A1 notes for data sources and equation 4 for details of the specifications.

III. Figures

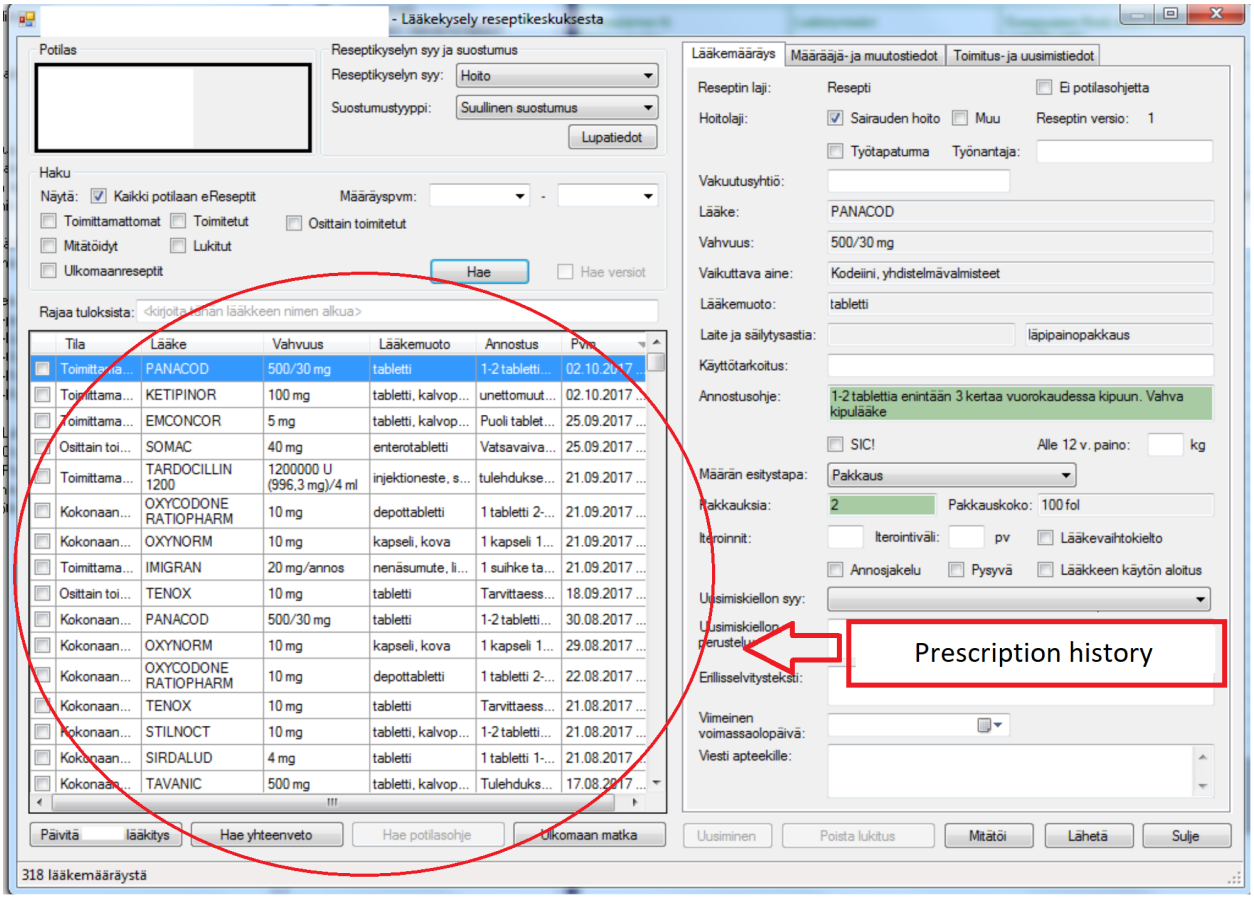

Figure A2
E-Prescribing Technology and Information Integration: Physician's View

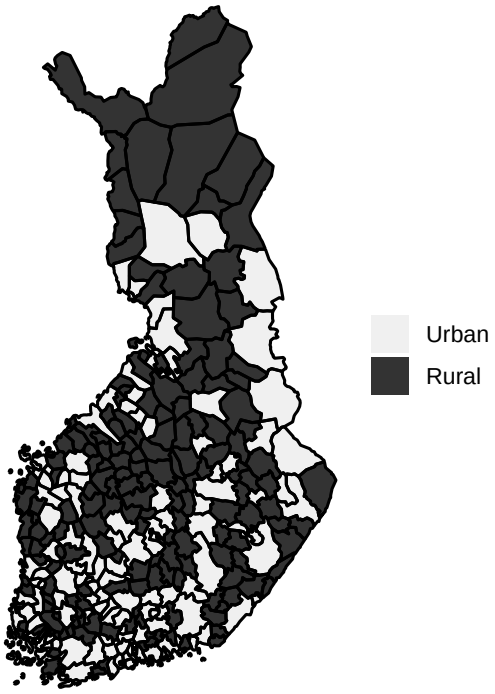

Figure A3
Regional Classification

Notes: This figure plots municipality groups (rural or semi-urban/urban), according to the official classification of Statistics Finland (2020). Statistics Finland defines rural municipalities as those in which less than 60 percent of the population live in urban settlements and in which the population of the largest urban settlement is less than 15,000 individuals; and those in which at least 60 percent but less than 90 percent of the population live in urban settlements and in which the population of the largest settlement is less than 4,000 individuals. Semi-urban municipalities are municipalities in which at least 60 percent but less than 90 percent of the population live in urban settlements and in which the population of the largest urban settlement is at least 4,000 but less than 15,000. Urban municipalities include those municipalities in which at least 90 percent of the population live in urban settlements or in which the population of the largest urban settlement is at least 15,000. In the analysis, we group together urban and semi-urban municipalities (and call them urban municipalities for brevity) because there is no apparent heterogeneity in the main effects of e-prescribing between these two groups (Section VII.A).

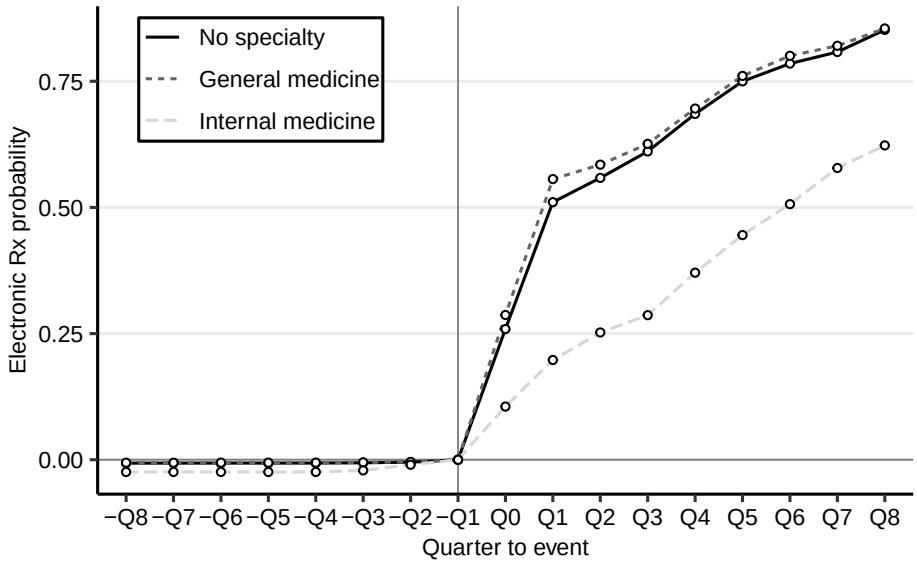

Figure A4

Take-up Rate of E-prescriptions, by Physician Speciality

Notes: This figure plots the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. Each line is plotted from a separate regression using data on the corresponding physician specializations. The outcome is a dummy variable that equals one if the prescription is an e-prescription.

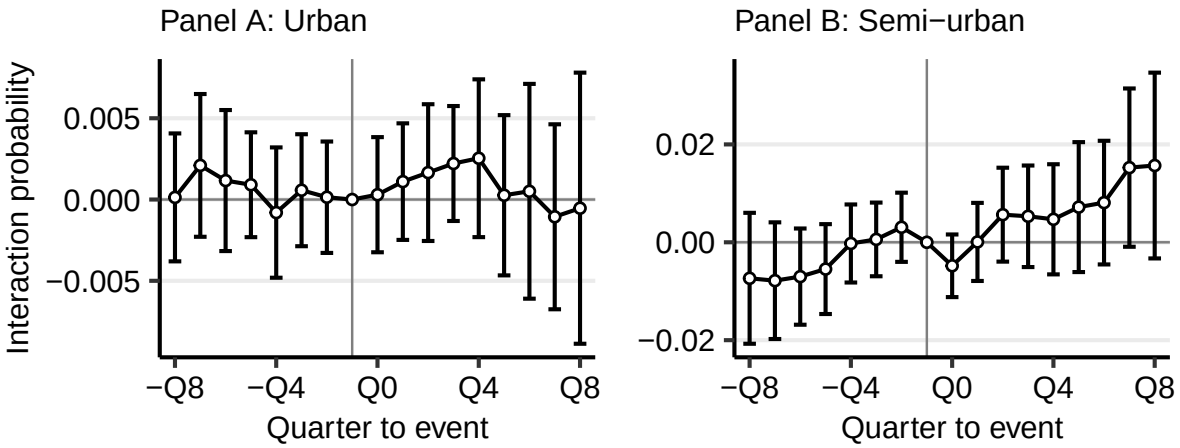

Figure A5

Probability of Warfarin-NSAID Interaction in Urban and Semi-Urban Municipalities

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. Panel A plots the results for the urban municipalities, and Panel B plots for semi-urban municipalities, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

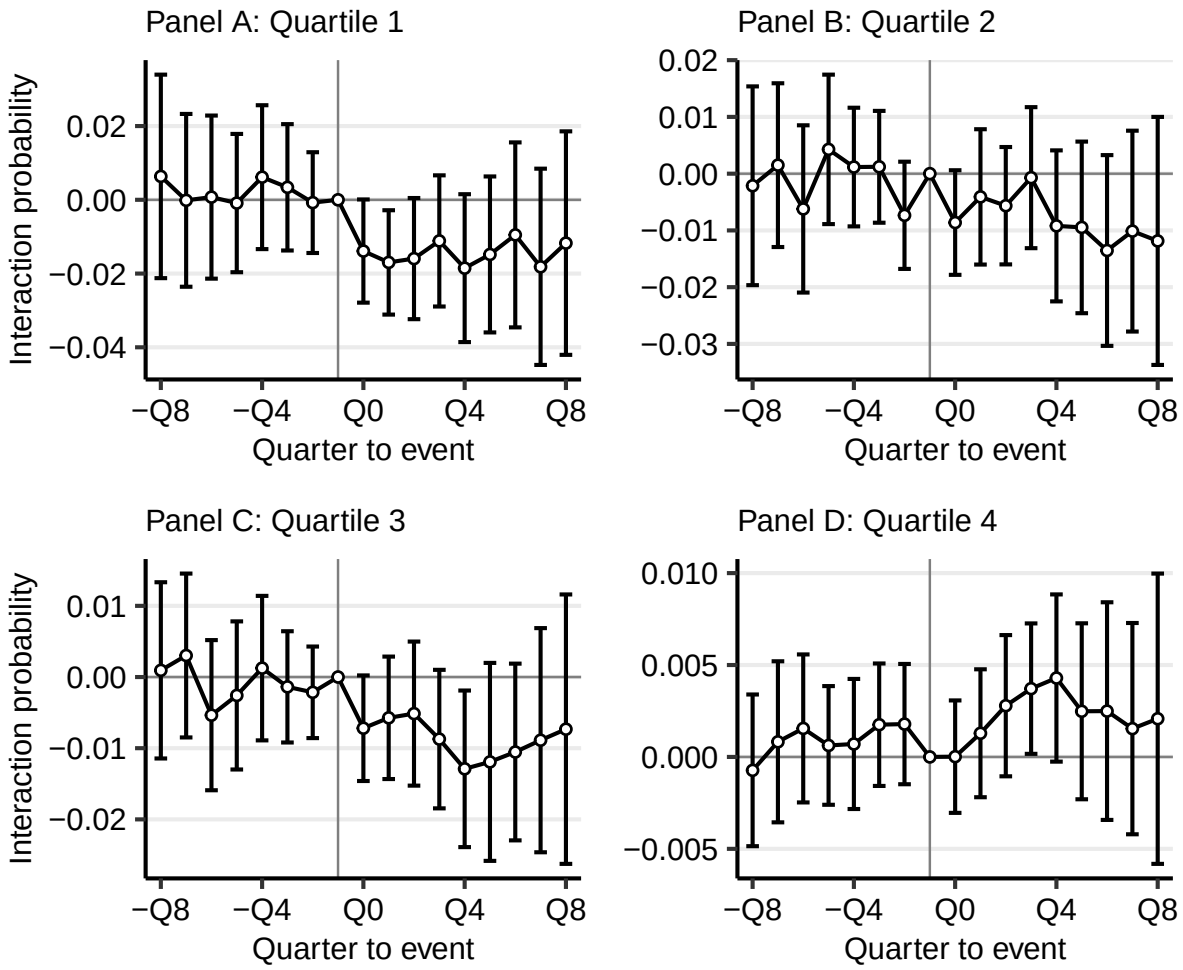

Figure A6

Probability of Warfarin-NSAID Interaction, by Number of Physicians in the Municipality

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. In the separate panels, municipalities are divided into ordered equal-sized ordered groups by the quartiles of the number of physicians in the municipalities in the pre-adoption period 2007–9. Panel A plots the results for municipalities in the first quartile and panel D for municipalities in the quartile. The standard errors are clustered at the municipality level.

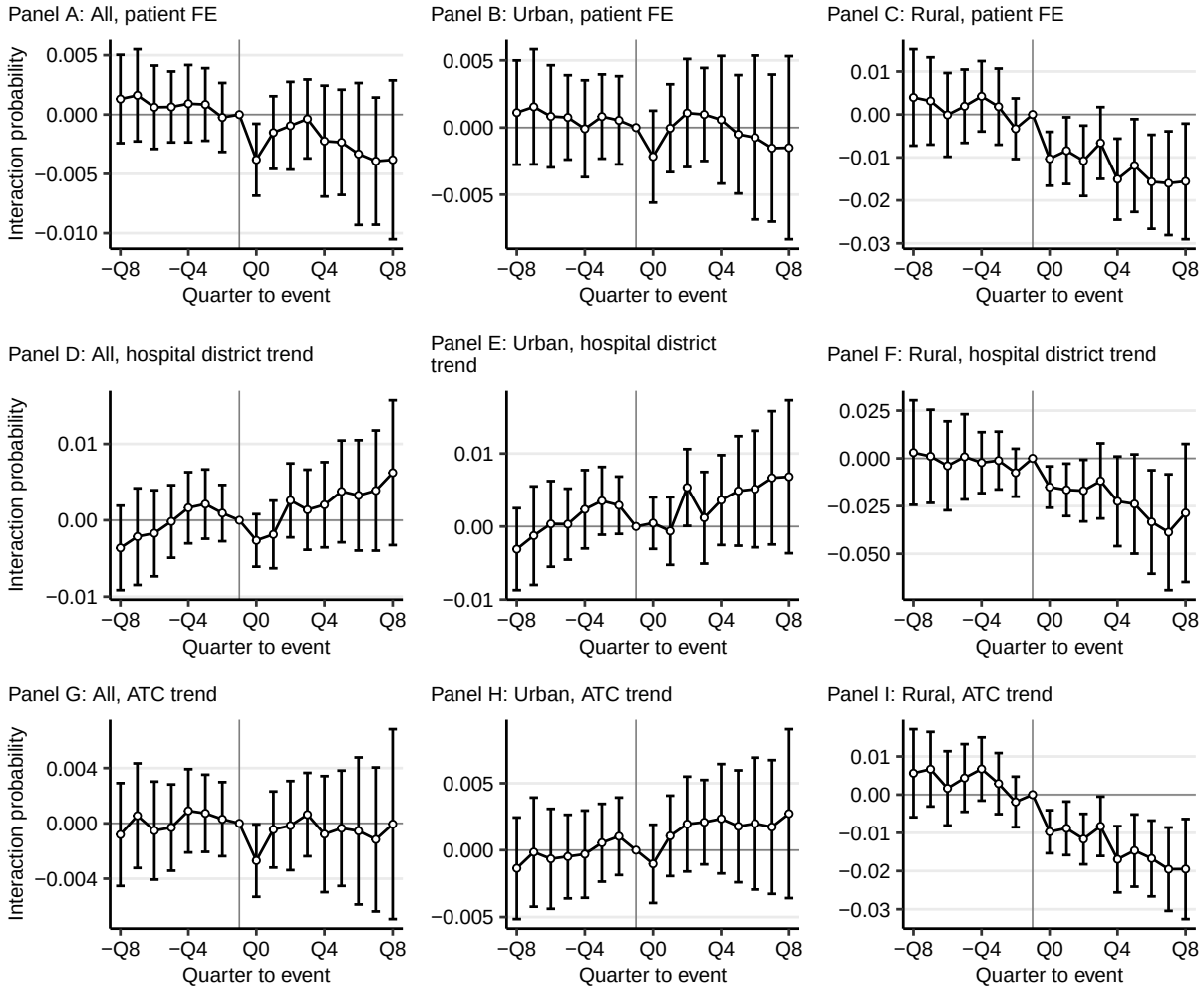

Figure A7

Probability of Interaction, Additional Robustness Checks to Baseline Results Part 1

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. Panels A, B, and C replace municipality fixed effects with patient fixed effects. Panels E, F, and G add interactions of hospital district and time fixed effects to the regressions. Panels G, H, and I plot the interaction probability with additional ATC code-specific linear time-trends added to the regressions. The first, second and third column of the panels plot the results using data on all municipalities, urban and semi-urban municipalities, and rural municipalities, respectively, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

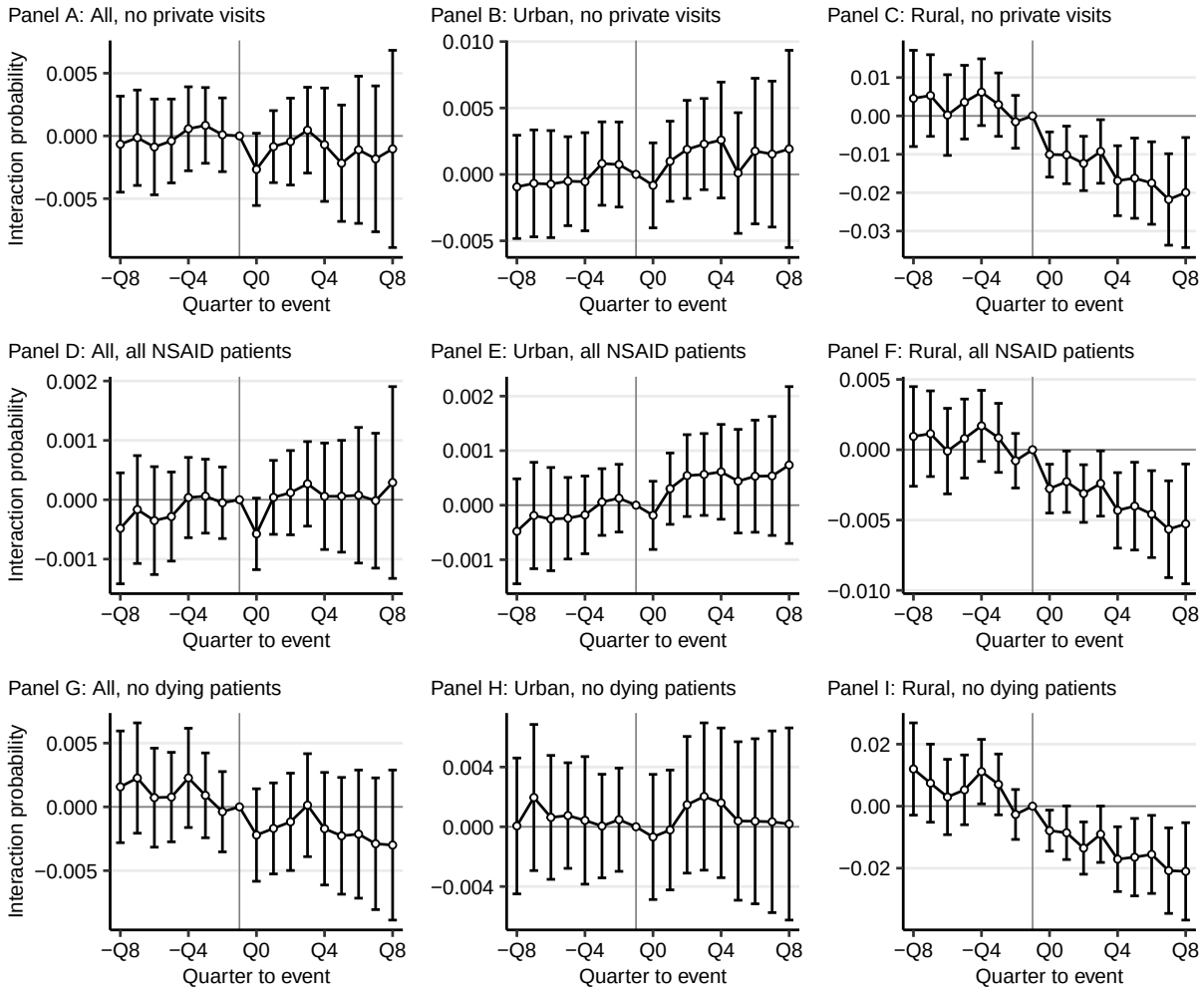

Figure A8

Probability of Interaction, Additional Robustness Checks to Baseline Results Part 2

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time trend fixed effects, age and age squared. Panels A, B, and C exclude all observations where the visit was to a private physician. Panels D, E, and F include all patients who have an NSAID prescription and who may not have a warfarin prescription during the periods in the data. Panels G, H, and I exclude all patients who died during the periods in the data. The first, second and third column of the panels plot the results using data on all municipalities, urban and semi-urban municipalities, and rural municipalities, respectively, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

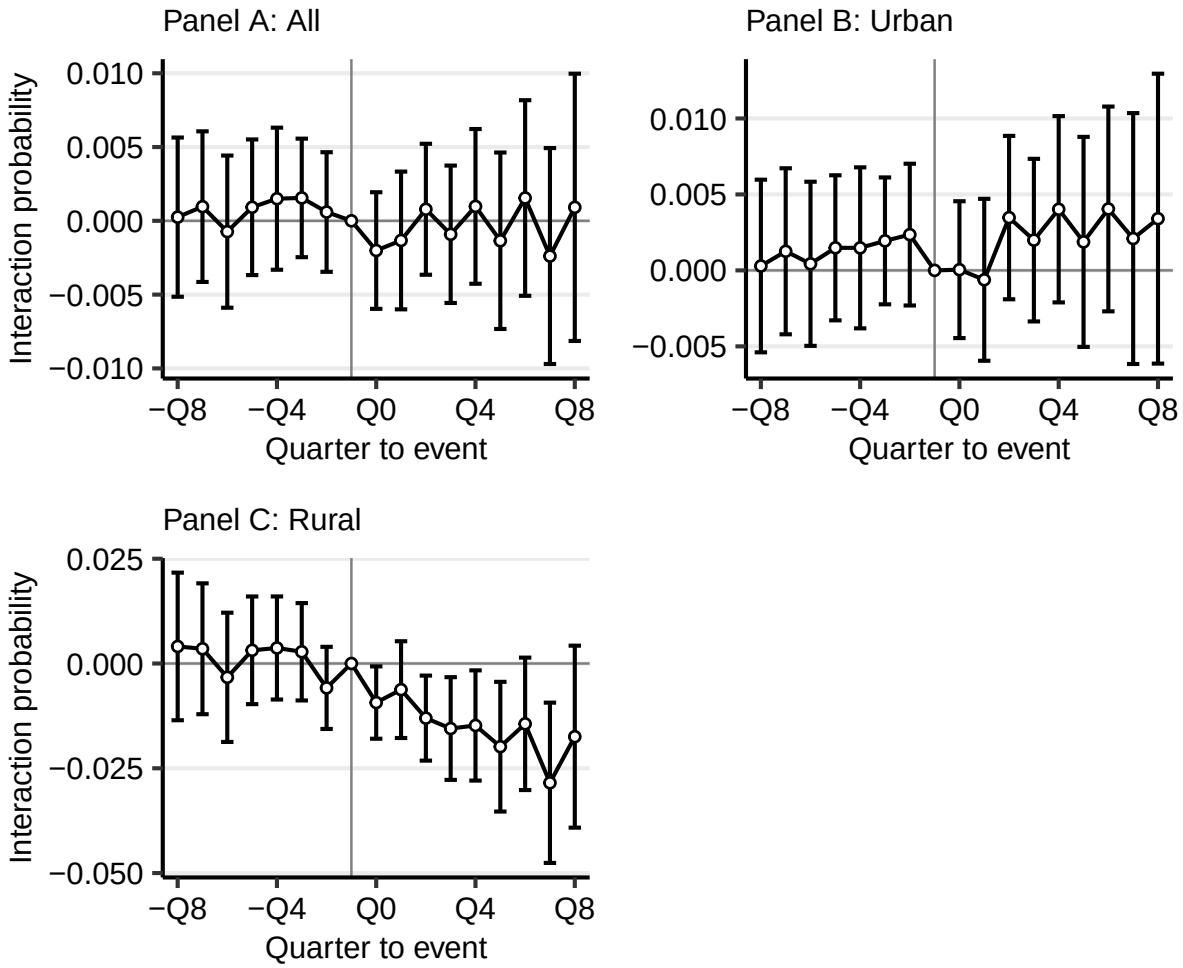

Figure A9

Probability of Interaction, Patients with Warfarin Prescription Before the Reform

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. The sample is limited to those patients who had a warfarin prescription before the first adoption of e-prescribing (April 2010). The first, second and third panel plot the results using data on all municipalities, urban and semi-urban municipalities, and rural municipalities, respectively, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

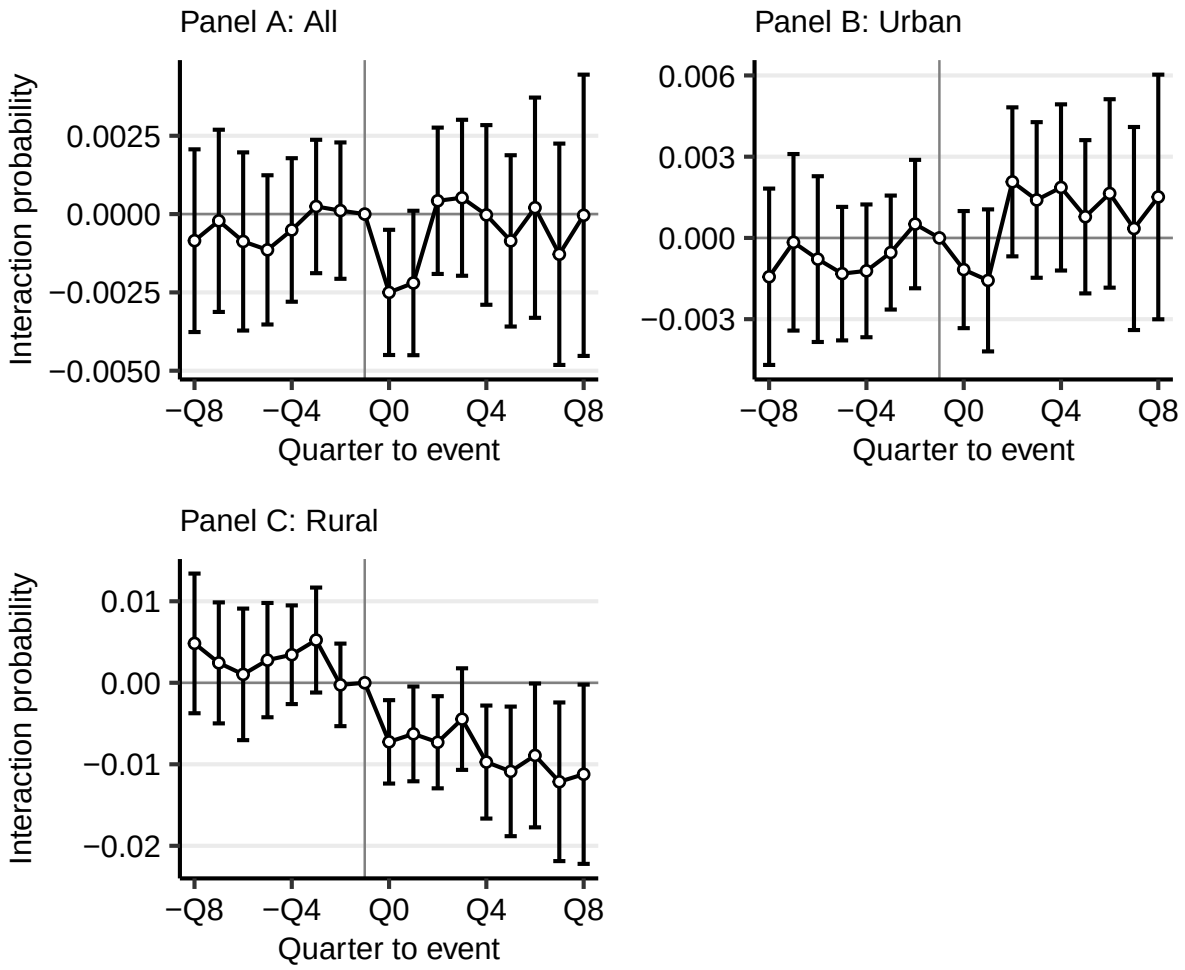

Figure A10

Probability of One-Way Warfarin-NSAID Interaction, By Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if an NSAID prescription interacts with another warfarin prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. Panel A plots the results for the whole sample of municipalities, Panel B plots for urban and semi-urban municipalities, and Panel C plots for rural municipalities, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

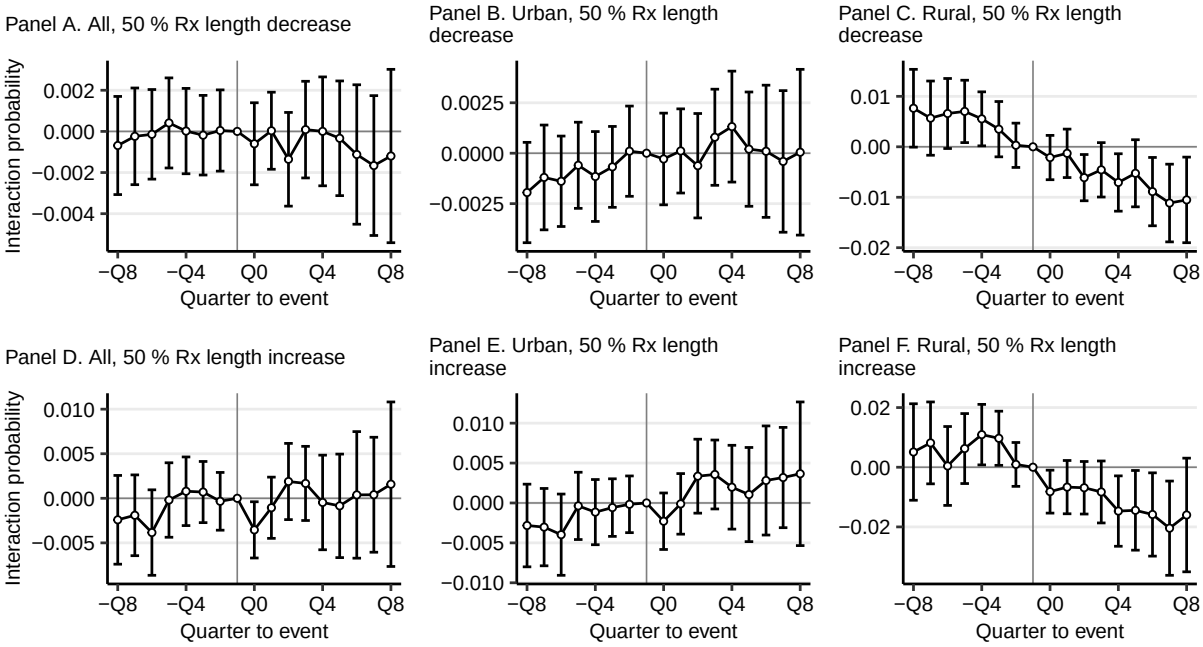

Figure A11

Sensitivity Test: Probability of Interaction, 50 Percent Reduction and Increase in Prescription Length

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients where the amount of defined daily doses in prescriptions has decreased by 50 percent. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. Panel A plots the results for the whole sample of municipalities, panel B plots for urban and semi-urban municipalities, and panel C plots for rural municipalities, according to the classification by Statistics Finland. The standard errors are clustered at the municipality level.

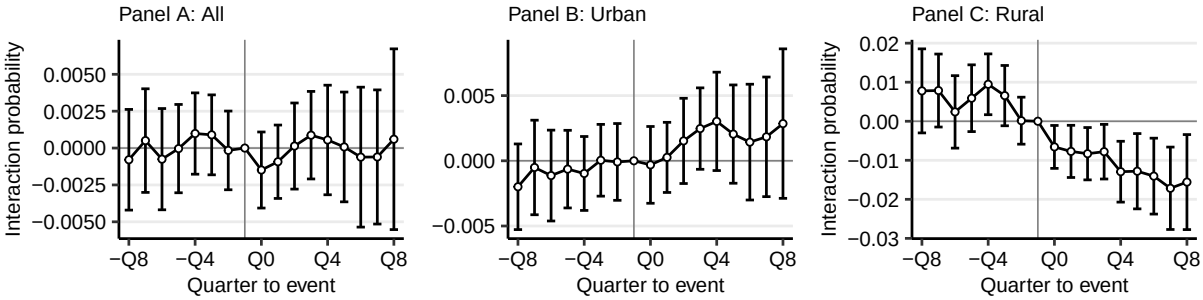

Figure A12

Sensitivity Test: Probability of Interaction, Interactions Under 10 Days and Over 100 Days Excluded

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients where prescriptions that interact for less than 10 days are dropped in Panels A, B, and C, and prescriptions that interact for over 100 days are dropped in Panels D, E, and F. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification is from Statistics Finland. The standard errors are clustered at the municipality level.

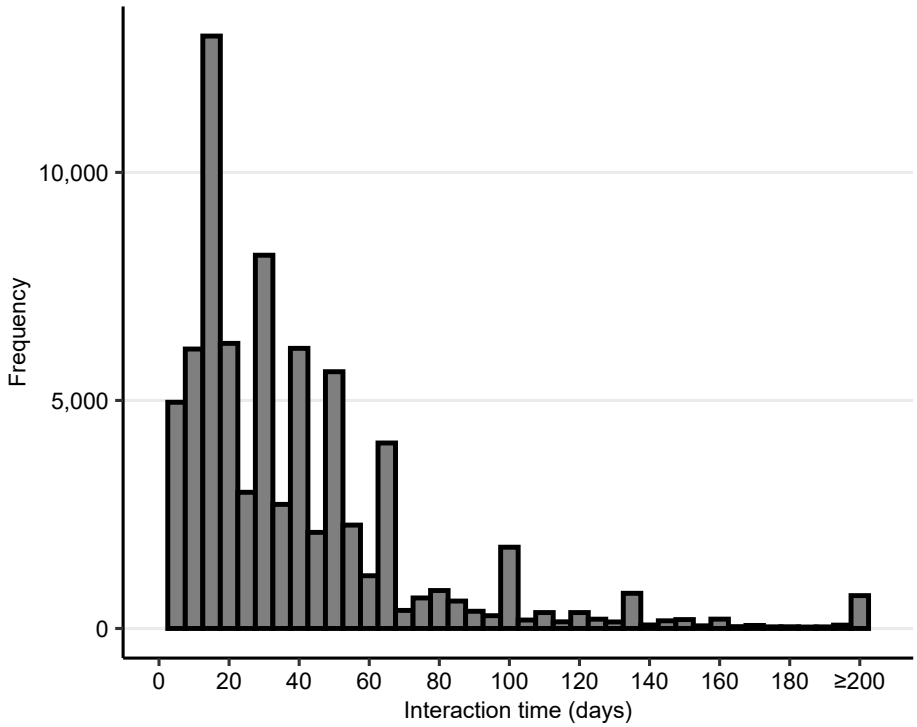

Figure A13
Duration of Warfarin-NSAID Interactions

Notes: The plot shows the conditional distribution of the duration of each overlapping warfarin and NSAID prescription, calculated in days. The length of warfarin and NSAID prescriptions is calculated using the number of defined daily doses of each prescription, where one day is assumed to equal one unit of daily dose. Bin width equals 5.

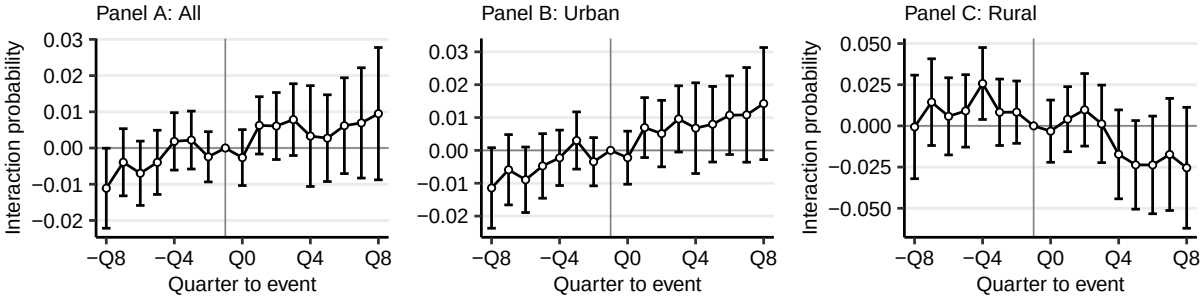

Figure A14

Probability of Warfarin-NSAID Interaction With Average Prescribing Intervals, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. Instead of defined daily doses, the prescription length is proxied by the patient and prescription type (warfarin or NSAID)-specific average prescribing intervals. Patients that do not have at least two warfarin or NSAID prescriptions are dropped. The maximum prescription length is capped at 180 days. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The omitted period is $-Q1$ and thus the coefficient estimates are relative to this period. The controls include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification is from Statistics Finland. The standard errors are clustered at the municipality level.

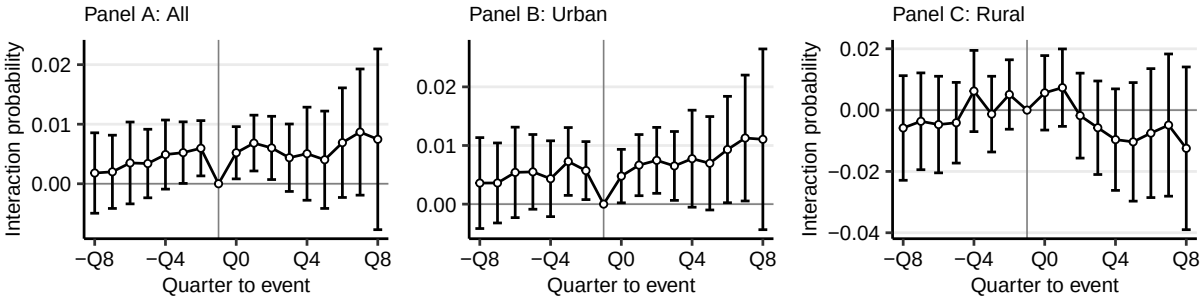

Figure A15

Placebo: Probability of Warfarin-Benzodiazepine Interaction, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (benzodiazepine) prescription interacts with a benzodiazepine (warfarin) prescription. See Figure 6 for more information on the specification of the model.

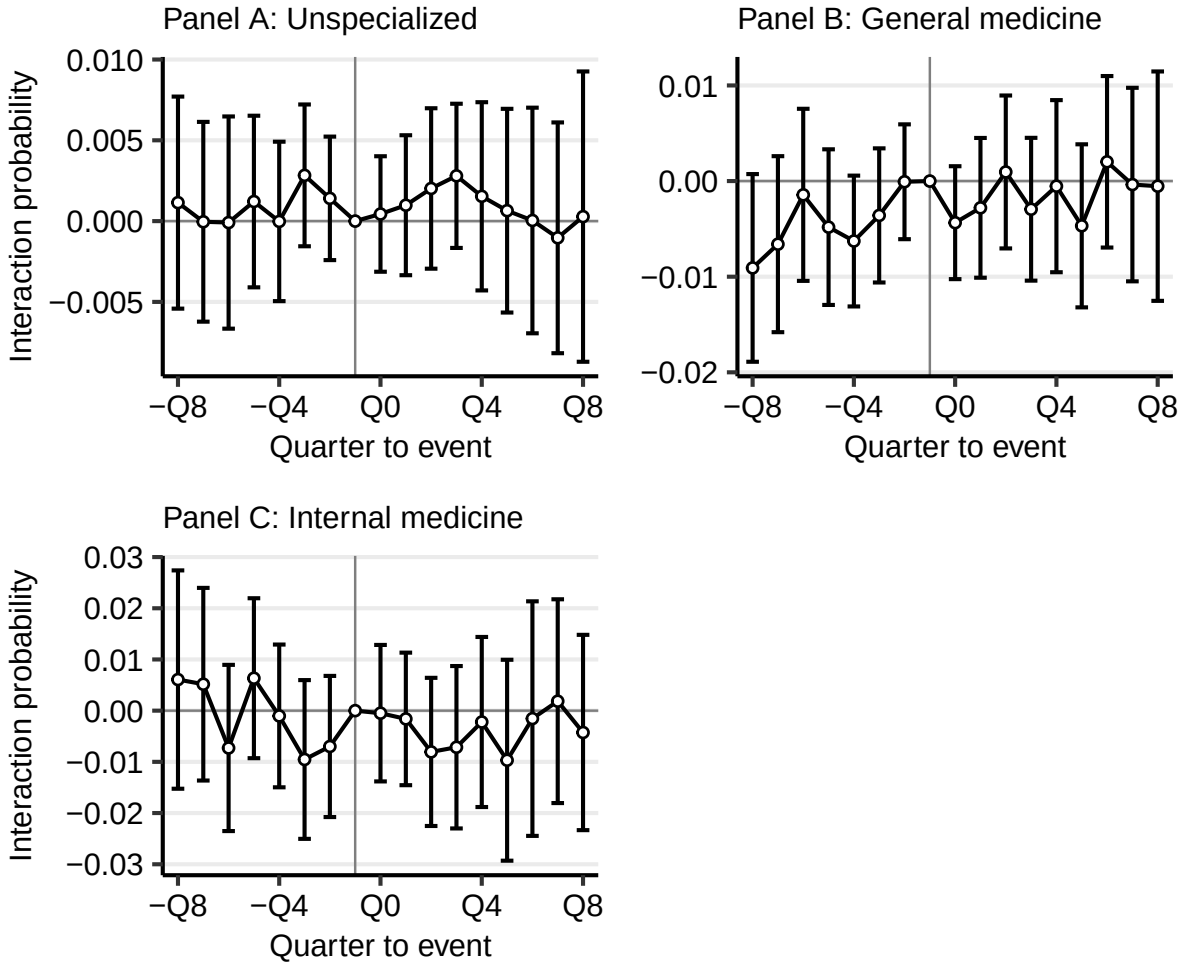

Figure A16

Probability of Warfarin-NSAID Interaction in Urban Municipalities, by Physician Speciality

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on warfarin patients in urban municipalities. Panels A, B, and C plot the results for prescriptions written by unspecialized physicians, and physicians specialized in general medicine and internal medicine, respectively. See Figure 6 for more information on the specification of the model.

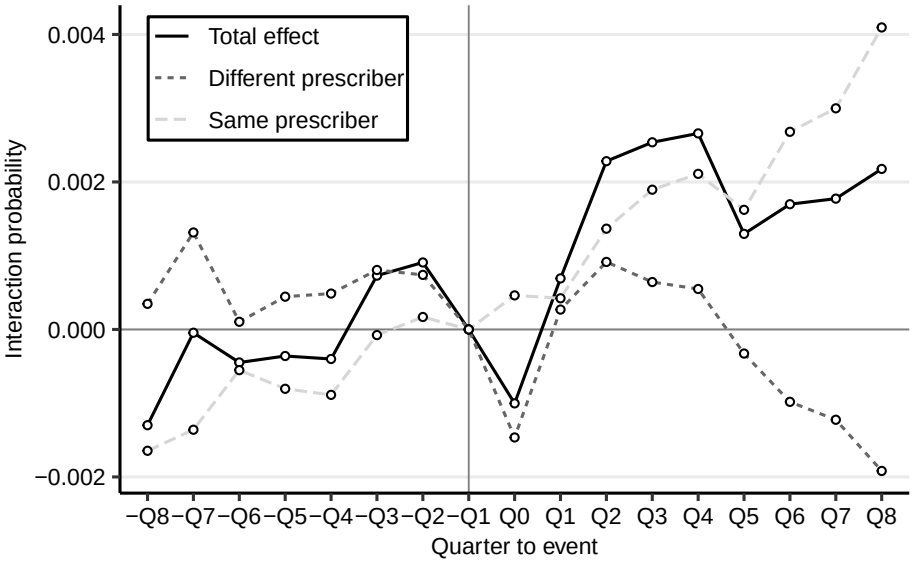

Figure A17

Probability of Warfarin-NSAID Interaction in Urban Municipalities, Different Versus Same Prescribing Physician

Notes: This figure plots the coefficient estimates from an event study framework using the prescription-level data on warfarin patients in urban municipalities. The outcome labeled "Total effect" is the baseline outcome and is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The outcome labeled "Different physician" adds an additional condition to the baseline outcome that the interacting prescriptions are written by different physicians. The outcome labeled "Same physician" adds an extra condition to the baseline outcome that the interacting prescriptions are written by the same physician. See Figure 6 for more information on the specification of the model.

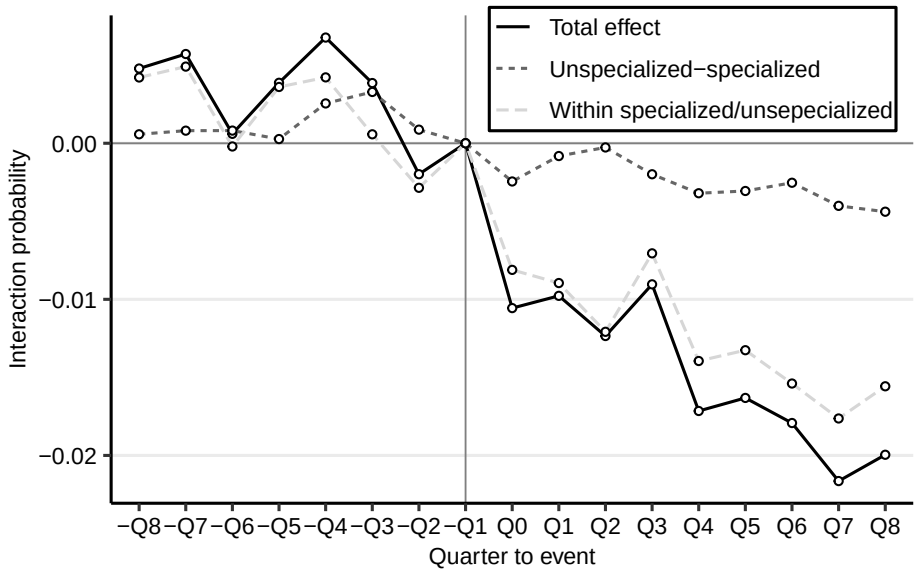

Figure A18

Probability of Warfarin-NSAID Interaction in Rural Municipalities, Within Versus Between Specializations

Notes: This figure plots the coefficient estimates from an event study framework using the prescription-level data on warfarin patients in rural municipalities. The outcome labeled "Total effect" is the baseline outcome and is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The outcome labeled "Within specialized/unspecialized" adds an additional condition to the baseline outcome that the interacting prescriptions are written by physicians within specialized-specialized or unspecialized-unspecialized pairs. The outcome labeled "Unspecialized-specialized" adds an extra condition to the baseline outcome that the interacting prescriptions are written by unspecialized-specialized physician pairs. In this figure, unspecialized physicians also include general medicine physicians. See Figure 6 for more information on the specification of the model.

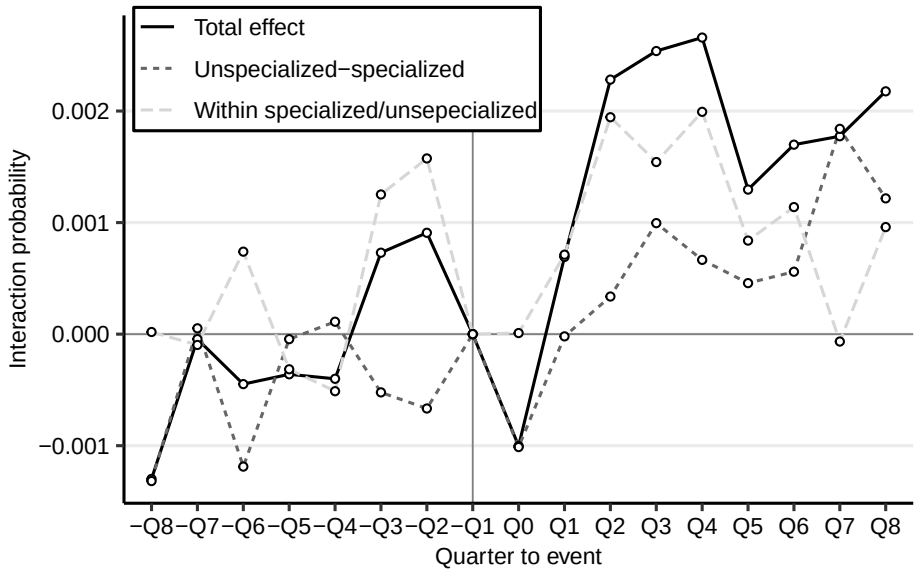

Figure A19

Probability of Warfarin-NSAID Interaction in Urban Municipalities, Within Versus Between Specializations

Notes: This figure plots the coefficient estimates from an event study framework using the prescription-level data on warfarin patients in urban municipalities. The outcome labeled "Total effect" is the baseline outcome and is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The outcome labeled "Within specialized/unspecialized" adds an additional condition to the baseline outcome that the interacting prescriptions are written by physicians within specialized-specialized or unspecialized-unspecialized pairs. The outcome labeled "Unspecialized-specialized" adds an extra condition to the baseline outcome that the interacting prescriptions are written by unspecialized-specialized physician pairs. In this figure, unspecialized physicians also include general medicine physicians. See Figure 6 for more information on the specification of the model.

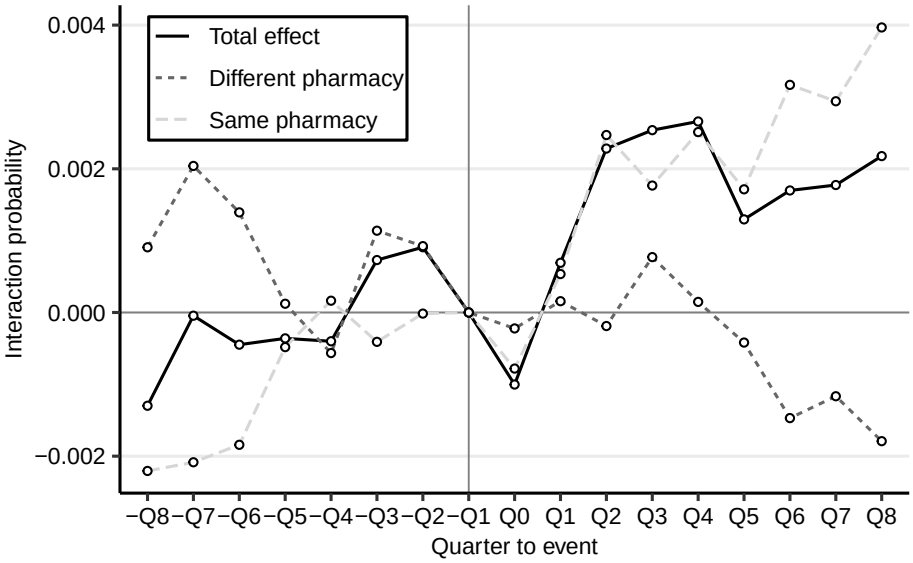

Figure A20

Probability of Warfarin-NSAID Interaction in Urban Municipalities, Different Versus Same Pharmacy

Notes: This figure plots the coefficient estimates from an event study framework using the prescription-level data on warfarin patients in urban municipalities. The outcome labeled "Total effect" is the baseline outcome and is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. The outcome labeled "Different pharmacy" adds an additional condition to the baseline outcome that the interacting prescriptions are fully filled at different pharmacies. The outcome labeled "Same pharmacy" adds an extra condition to the baseline outcome that the interacting prescriptions are (at least partly) filled at the same pharmacy. See Figure 6 for more information on the specification of the model.

IV. Tables

Table A2

Prescription Counts and Shares by Physician Speciality for Pre-Adoption Period 2007–9

	All municipalities		Urban		Rural	
	N	Share	N	Share	N	Share
Warfarin	357,114	0.74	284,006	0.74	73,108	0.72
Unspecialized	171,165	0.48	130,632	0.46	40,533	0.55
General medicine	76,014	0.21	60,237	0.21	15,777	0.22
Internal medicine	22,346	0.06	19,183	0.07	3,163	0.04
NSAID	127,133	0.26	98,817	0.26	28,316	0.28
Unspecialized	59,796	0.47	44,758	0.45	15,038	0.53
General medicine	24,272	0.19	18,361	0.19	5,911	0.21
Internal medicine	4,005	0.03	3,381	0.03	624	0.02
Interacting Rx	34,970	0.07	26,811	0.07	8,159	0.08
Unspecialized	16,178	0.46	11,987	0.45	4,191	0.51
General medicine	6,760	0.19	4,943	0.18	1,817	0.22
Internal medicine	1,999	0.06	1,691	0.06	308	0.04

Notes: The numbers are based on patients with at least one warfarin prescription in the period of 2007–9.

Table A3

Effects of E-prescribing on Warfarin-NSAID Interaction With Average Prescribing Intervals, by Municipality Group

	All municipalities (1)	Urban (2)	Rural (3)
Short-run	0.002	0.003	−0.006
	(0.004)	(0.004)	(0.008)
Long-run	−0.001	0.004	−0.031***
	(0.007)	(0.007)	(0.011)
Mean outcome	0.083	0.080	0.092
Observations	444,111	355,071	89,040

Notes: This table reports the coefficients from difference-in-differences regressions using the prescription-level data on warfarin patients. Instead of defined daily doses, the prescription length is proxied by the patient and prescription type (warfarin or NSAID)-specific average prescribing intervals. Patients who do not have at least two warfarin or NSAID prescriptions are dropped. The maximum prescription length is capped at 180 days. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. "Short-run" refers to the first year after adoption, and "Long-run" refers to all subsequent periods. Each column is estimated from a separate regression. All specifications include municipality fixed effects, time fixed effects, and age and age squared. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A4

Effects of E-prescribing on Warfarin-NSAID Interaction, by Municipality Group and Physician Specialty

	All municipalities (1)	Urban (2)	Rural (3)
Panel A. Unspecialized			
Short-run	−0.002	0.000	−0.012***
	(0.001)	(0.001)	(0.003)
Long-run	−0.004*	−0.001	−0.018***
	(0.002)	(0.002)	(0.005)
Mean outcome	0.043	0.042	0.047
Observations	917,214	709,548	207,666
Panel B. General medicine			
Short-run	−0.003	−0.002	−0.008
	(0.002)	(0.002)	(0.006)
Long-run	−0.004	−0.002	−0.010
	(0.003)	(0.003)	(0.007)
Mean outcome	0.040	0.038	0.049
Observations	337,702	266,726	70,976
Panel C. Internal medicine			
Short-run	−0.001	0.001	−0.023
	(0.004)	(0.005)	(0.015)
Long-run	0.001	0.004	−0.030
	(0.007)	(0.007)	(0.024)
Mean outcome	0.056	0.055	0.063
Observations	73,862	63,477	10,385

Notes: This table reports the coefficients from difference-in-differences regressions using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. "Short-run" refers to the first year after adoption, and "Long-run" refers to all subsequent periods. Each panel-column combination is estimated from a separate regression. All specifications include municipality fixed effects, time fixed effects, and age and age squared. Panel A uses prescriptions written by physicians without any specialization, Panel B by physicians specialized in general medicine, and Panel C by physicians specialized in internal medicine. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A5
Effects of E-prescribing on Warfarin-NSAID Interaction, Different Versus Same prescribing Physician

	All municipalities (1)	Urban (2)	Rural (3)
Short-run × same physician	0.000	0.001	−0.002
	(0.000)	(0.000)	(0.002)
Long-run × same physician	0.000	0.001	−0.004**
	(0.001)	(0.001)	(0.002)
Short-run × different physician	−0.002**	−0.001	−0.008***
	(0.001)	(0.001)	(0.003)
Long-run × different physician	−0.003**	−0.003*	−0.009**
	(0.001)	(0.002)	(0.004)

Notes: This table reports the coefficients from difference-in-differences regressions using the prescription-level data on warfarin patients. The outcome is a dummy variable that equals one if a warfarin (NSAID) prescription interacts with another NSAID (warfarin) prescription. "Short-run × same physician" and "Long-run × same physician" refer to the interaction between drug interactions where the prescribing physician is the same as the previous prescribing physician and, respectively, the first year after adoption and all subsequent periods after adoption. "Short-run × different physician" and "Long-run × different physician" refer to the same interactions but when the interacting prescription is written by a different physician than the prescriber of the underlying prescription. The coefficients for different physician are estimated relative to the coefficients of same physician, meaning that the total effect for different physician is the sum of coefficients of same physician and different physician. Each column is estimated from a separate regression. All specifications include municipality fixed effects, time fixed effects, and age and age squared. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

V. Identification in the Early Versus Later Treated Municipalities

Goodman-Bacon (2021) shows that, in the case of a staggered adoption of policy where the treatment occurs at different times across units, the two-way fixed effects DiD estimator is a weighted average of all possible individual two-period/two-group DiD estimators in the data. In the case of dynamic treatment effects, this could induce negative weights to later-treated groups as these units are compared to already-treated units.

We follow Goodman-Bacon (2021) to examine the potential bias in the overall DiD estimates in the quality of prescribing stemming from the later-treated municipalities. Specifically, we perform

an explicit decomposition of the summed weights and average DiD estimates for early- versus later-treated municipalities and later- versus early-treated municipalities. The shortcoming of this approach is that as such it does not allow us to partition the treatment effect into short- and long-run effects as in our main analysis.[1] To reduce the computational burden, as we have to compute all two-by-two DiD estimates separately for each municipality group (urban and rural) and adoption time, we use aggregated municipality-quarter-level data and the log number of warfarin-NSAID interactions as an outcome. Thus, the estimates are not fully comparable to our baseline estimates obtained from the prescription-level data, but the results should give an idea of whether using early-treated municipalities as a control group is worrisome in our setting.

The results for the municipality-level DiD estimates and the decompositions beneath them are shown in Tables A6. We find that the number of warfarin-NSAID interactions decreases by 14 percent in rural municipalities and there is no statistically significant effect in urban municipalities. Based on the decompositions, we conclude that negative weighting is not a major issue, especially in rural municipalities. Although not fully comparable, our conclusions regarding the effects of e-prescribing based on the aggregated data remain fairly similar to those drawn from our baseline estimates using the prescription-level data.

Table A6

Goodman-Bacon Analysis on the Number of Interactions in Municipality

	All municipalities (1)	Urban (2)	Rural (3)
DiD	-0.066^{**}	0.031	-0.140^{***}
	(0.029)	(0.034)	(0.042)
Observations	9,728	3,872	5,856
Adjusted R^2	0.78	0.823	0.502
Earlier vs. Later (Weight $\times$ DiD)	0.693$\times$-0.064	0.686$\times$0.054	0.698$\times$-0.149
Later vs. Earlier (Weight $\times$ DiD)	0.307$\times$-0.071	0.314$\times$-0.019	0.302$\times$-0.119

Notes: This table reports the coefficients from difference-in-differences regressions using municipality-quarter-level balanced data. The outcome is the log number of interactions in the municipality. "DiD" is the binary variable for the treatment effect and it gets the value of one after the municipality gets treated. "Earlier vs. Later" and "Later vs. Earlier" show the summed weights and the average DiD coefficients from all two-by-two decompositions of earlier and later adopting municipalities, respectively. All regressions include municipality fixed effects and time fixed effects. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

[1] Another shortcoming is that the approach does not allow for weights in the regressions when doing the full decomposition.

VI. Prescription Drug Use and Health Outcome

A. Prescription Drug Use and Change in the Composition of Patient Population

We analyze the effects on prescription drug use to get a broader picture of the effects of e-prescribing and of the underlying mechanisms such as changes in the patient population. E-prescribing can either decrease (better monitoring) or increase prescription drug use (easier renewal and decreased hassle costs), see Section III.B. If more drugs are being prescribed, there is a greater chance that there will be an interaction among the drugs. The effect is obviously the opposite if e-prescribing leads to less drugs being prescribed.

We analyze the effects on the intensive and extensive margins of prescription drug use. The intensive margin (prescription size) is measured by the number of defined daily doses per prescription. The extensive margin is measured by the total number of new and repeat prescriptions that a patient has in a given quarter. In the extensive margin analysis we aggregate the data to the patient-quarter-level balanced panel.

We find that the size of warfarin prescriptions increases by 4 percent in urban regions and by 6 percent in rural regions in the long run after e-prescribing, as shown in Figure A21 and Table A7. However, the effects are overestimated in the two municipality groups because the prescription size is smaller one quarter before the adoption of e-prescribing ($-Q1$) than in the previous periods.[2] We interpret this decrease as being consistent with anticipation effects, with physicians writing shorter warfarin prescriptions in $-Q1$ as they expected that patients would benefit from the new technology. However, because prescriptions were shorter, physicians had to renew more prescriptions in the periods immediately following the adoption of e-prescribing. Consistent with this, we find that the number of a patient's warfarin prescriptions increases by approximately 1 percent in the short run after e-prescribing, but remains close to zero in the long run in the two municipality groups.[3]

[2] If we omit the period $-Q1$ from the sample, the long-run increase is 2 percent in urban regions and 3 percent in rural regions, and the latter effect is statistically insignificant (Table A8). Moreover, we have checked that the decrease in prescription size is not mechanically caused by the event study design and its normalization. The decrease occurs in $-Q1$ even if we normalize a different period than $-Q1$ to zero.

[3] Our extensive margin results are robust to using the inverse hyperbolic sine transformation.

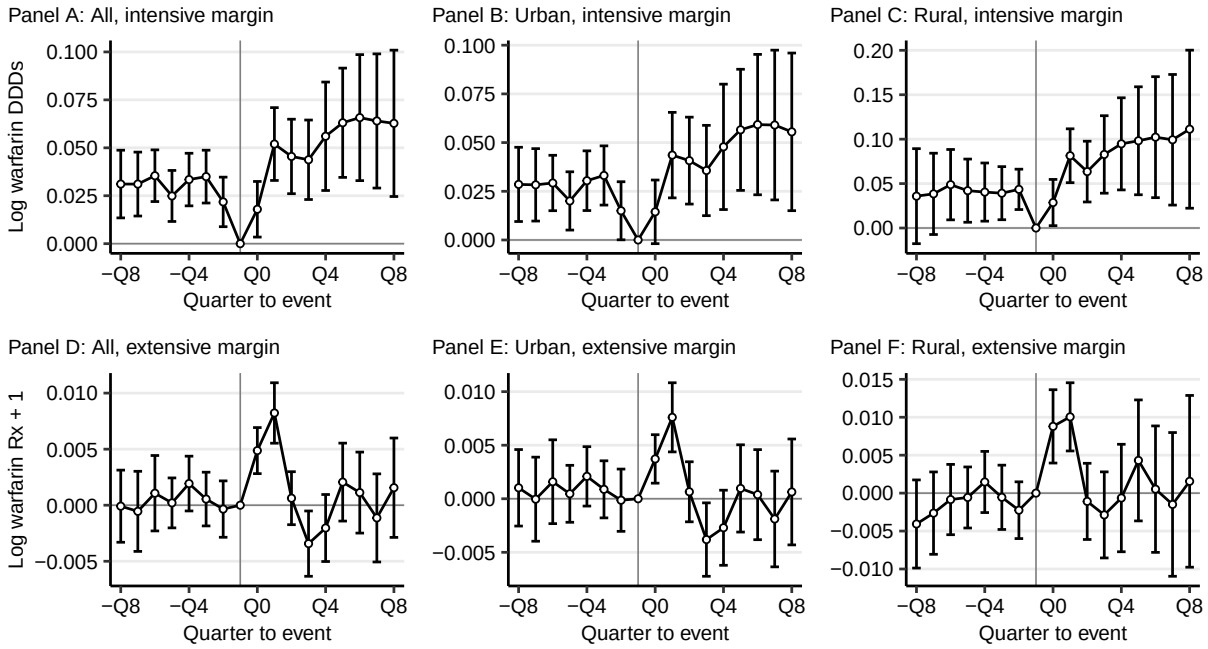

Figure A21

Intensive and Extensive Margins of Warfarin Prescriptions, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data (Panels A–C) and patient-quarter-level balanced data (Panels D–F) on warfarin patients. In Panels A–C, the intensive margin outcome is the log number of defined daily doses of warfarin prescriptions, and the data include only warfarin prescriptions. In Panels D–F, the extensive margin outcome is the log number of warfarin prescriptions$+1$ to adjust for zeros in the balanced panel. The controls include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification is from Statistics Finland. The standard errors are clustered at the municipality level.

Figure A22 and Table A9 show no statistically significant effect on the intensive and extensive margins of NSAID use in urban regions. In rural regions physicians write smaller NSAID prescriptions after e-prescribing, but they do not increase the quarterly number of NSAID prescriptions for warfarin patients.

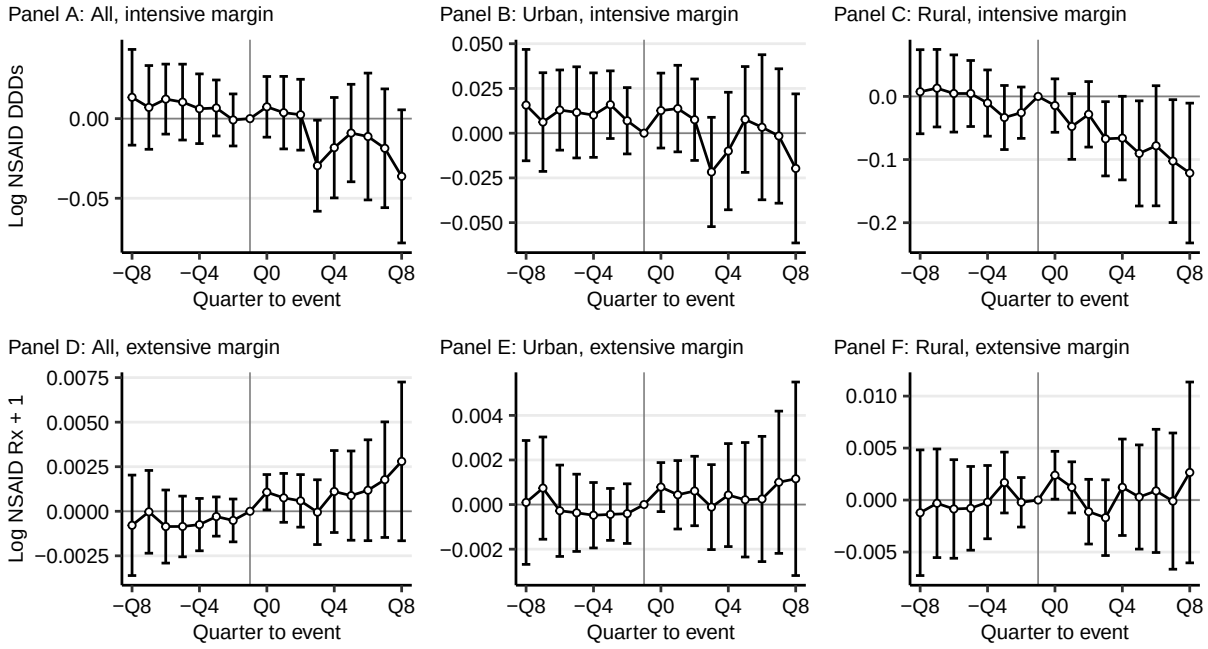

Figure A22

Intensive and Extensive Margins of NSAID Prescriptions, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data (panels A–C) and patient-quarter-level balanced data (panels D–F) on warfarin patients. In Panels A–C, the intensive margin outcome is the log number of defined daily doses of NSAID prescriptions, and the data include only NSAID prescriptions. In Panels D–F, the extensive margin outcome is the log number of NSAID prescriptions$+1$ to adjust for the zeros in the balanced panel. The controls include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A7

Intensive and Extensive Margins of Warfarin Prescriptions, by Municipality Group

	All municipalities (1)	Urban (2)	Rural (3)
Panel A. Intensive margin: Log warfarin DDDs			
Short-run	0.018**	0.016*	0.029**
	(0.008)	(0.009)	(0.012)
Long-run	0.038***	0.035**	0.056**
	(0.013)	(0.014)	(0.023)
Mean outcome	140.086	140.548	138.234
Observations	1,050,380	840,392	209,988
Panel B. Extensive margin: Log warfarin prescriptions			
Short-run	0.003***	0.003***	0.006***
	(0.001)	(0.001)	(0.002)
Long-run	0.002*	0.001	0.005
	(0.001)	(0.001)	(0.003)
Mean outcome	3.103	3.102	3.107
Observations	7,422,752	5,952,632	1,470,120

Notes: This table reports the coefficients from difference-in-differences regressions using the prescription-level data in Panel A and patient-quarter-level balanced data in Panel B on warfarin patients. In Panel A the outcome is the log number of defined daily doses of warfarin prescriptions, and the data include only warfarin prescriptions. In Panel B, the outcome is the log number of warfarin prescriptions$+1$ to adjust for the zeros in the balanced panel. "Short-run" refers to the first year after adoption, and "Long-run" refers to all subsequent periods. Each panel-column combination is estimated from a separate regression. All specifications include municipality fixed effects, time fixed effects, and age and age squared. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A8

Intensive Margin of Warfarin Prescriptions Without $-Q1$, by Municipality Group

	All municipalities (1)	Urban (2)	Rural (3)
Short-run	0.003	0.002	0.007
	(0.006)	(0.007)	(0.015)
Long-run	0.021*	0.021*	0.030
	(0.011)	(0.012)	(0.025)
Mean outcome	139.921	140.369	138.129
Observations	1,015,591	812,526	203,065

Notes: This table shows the intensive margin results for warfarin prescriptions with the first pre-quarter of e-prescribing, $-Q1$, dropped from the data. See Table A7 for more information on the specification.

Table A9

Intensive and Extensive Margins of NSAID Prescriptions, by Municipality Group

	All municipalities (1)	Urban (2)	Rural (3)
Panel A. Intensive margin: Log NSAID DDDs			
Short-run	0.000	0.003	−0.013
	(0.008)	(0.009)	(0.018)
Long-run	−0.008	0.000	−0.046
	(0.011)	(0.011)	(0.034)
Mean outcome	53.036	52.607	54.677
Observations	639,126	506,806	132,320
Panel B. Extensive margin: Log NSAID prescriptions			
Short-run	0.001	0.001	0.000
	(0.001)	(0.001)	(0.001)
Long-run	0.001	0.001	0.001
	(0.001)	(0.001)	(0.002)
Mean outcome	2.952	2.950	2.963
Observations	7,422,752	5,952,632	1,470,120

Notes: This table reports the coefficients from difference-in-differences regressions using the prescription-level data in Panel A and patient-quarter-level balanced data in Panel B on warfarin patients. In Panel A the outcome is the log number of defined daily doses of NSAID prescriptions, and the data include only NSAID prescriptions. In Panel B, the outcome is the log number of NSAID prescriptions+1 to adjust for the zeros in the balanced panel. "Short-run" refers to the first year after adoption, and "Long-run" refers to all subsequent periods. Each panel-column combination is estimated from a separate regression. All specifications include municipality fixed effects, time fixed effects, and age and age squared. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

E-prescribing could affect initial warfarin prescriptions, and thereby change the warfarin patient population. Another benefit of this approach is that the dependent variable is scaled in a welfare-relevant way.[4] Table A10 shows separately the effects on the number of all and new warfarin prescriptions per municipality and quarter, using aggregated data and population weights in the estimation. We find the point estimates to be small and imprecisely estimated, especially for the outcome of new warfarin use. However, for the quarterly number of warfarin prescriptions, the imprecise point estimates suggest a 3–6 percent increase in rural municipalities. Overall, the extensive margin adjustments are much smaller compared to the main effects on harmful drug combinations.

Theoretically, e-prescribing could change the composition of the patient population through the extensive margin adjustments. This poses a potential threat for the identification of the main effects using prescription-level data. For example, if warfarin users were less likely to need NSAIDs after e-prescribing, the coefficients of interest would reflect the change in the patient composition rather than the true effects of information on the interaction probability.[5] Therefore, as an additional check, we also estimate regressions for the total number of warfarin-NSAID interactions per municipality and quarter, as shown in Table A10. Using municipality aggregates, we estimate the effects without any concern about the potential effects of compositional changes. Consistent with our main results, e-prescribing decreases the number of interactions by 19 percent in the long run in rural municipalities and the effect is statistically significant. Table A11 additionally confirms that the characteristics of new warfarin patients and their prescriptions look fairly similar one year before versus one year after the adoption of e-prescribing.[6]

[4] A challenge of switching the unit of observation to a municipality-quarter level is how to pursue the heterogeneity analyses around the number of prescribing doctors and pharmacies.

[5] Note that our main results are robust to limiting the data to the fixed set of patients who received a warfarin prescription before e-prescribing, as discussed in Section VII.A and shown in Online Appendix Figure A9.

[6] Migration between urban and rural regions may change the compositions of the urban and rural populations. However, the fraction of patients who have changed their status in terms of urban and rural region is only 1.3 percent, and the fraction of patients who have changed their municipality is 4.4 percent, respectively. Our results remain intact when we exclude the patients (4.4 percent) who have changed their municipality over the estimation period.

Table A10

Extensive Margin of Warfarin Use and Interactions in Municipality

	All municipalities (1)	Urban (2)	Rural (3)
Panel A. Log number of new patients			
Short-run	0.007	−0.013	0.019
	(0.023)	(0.025)	(0.034)
Long-run	0.018	−0.001	0.027
	(0.032)	(0.034)	(0.050)
Observations	7,296	2,904	4,392
Adjusted R^2	0.872	0.921	0.572
Panel B. Log number of warfarin prescriptions			
Short-run	0.032**	0.027*	0.033
	(0.016)	(0.015)	(0.025)
Long-run	0.050*	0.034	0.056
	(0.026)	(0.023)	(0.041)
Observations	7,296	2,904	4,392
Adjusted R^2	0.945	0.972	0.827
Panel C. Log number of interactions			
Short-run	−0.054**	0.040	−0.124***
	(0.027)	(0.038)	(0.035)
Long-run	−0.056	0.126*	−0.188***
	(0.044)	(0.069)	(0.055)
Observations	9,728	3,872	5,856
Adjusted R^2	0.727	0.776	0.419

Notes: This table reports the coefficients from difference-in-differences regressions using municipality-quarter-level balanced data. In Panel A, the outcome is the log number of new warfarin patients. New patients are defined as those patients who have their first warfarin prescription in a given quarter in the data. In Panel B, the outcome is the log number of overall warfarin prescriptions in the municipality. In Panel C, the outcome is the log number of warfarin-NSAID interactions. In Panels A and B, because of left-censoring, those patients who have their first warfarin prescription in 2007–2009 are dropped and only data for the years 2009–14 are used in the regressions. "Short-run" refers to the first year after adoption, and "Long-run" refers to all subsequent periods. All regressions include fixed effects for municipality and time trend. All regressions are weighted by the population size in the municipality. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A11

Summary Statistics for New Patients in Pre- and Post-Adoption Years

	Urban		Rural	
	Pre-adoption	Post-adoption	Pre-adoption	Post-adoption
Warfarin DDDs per patient	181.008	188.077	176.905	185.715
	(120.254)	(123.949)	(119.651)	(117.267)
Warfarin Rx per patient	1.510	1.482	1.502	1.450
	(0.748)	(0.702)	(0.769)	(0.702)
DDDs in first warfarin Rx	118.017	121.372	119.025	123.918
	(79.547)	(83.033)	(83.252)	(83.256)
NSAID DDDs per patient	18.913	18.244	20.896	19.701
	(51.600)	(51.985)	(56.474)	(56.687)
NSAID Rx per patient	0.390	0.363	0.413	0.363
	(0.815)	(0.799)	(0.899)	(0.809)
DDDs in first NSAID Rx	12.778	12.372	12.952	12.885
	(32.895)	(31.826)	(33.475)	(34.660)
Share of Rx by specialty				
Unspecialized	0.568	0.603	0.631	0.668
	(0.425)	(0.422)	(0.419)	(0.408)
General medicine	0.118	0.126	0.139	0.139
	(0.268)	(0.279)	(0.295)	(0.295)
Internal medicine	0.069	0.070	0.060	0.051
	(0.223)	(0.225)	(0.206)	(0.196)
Age	67.750	68.463	70.206	70.684
	(14.698)	(14.545)	(13.665)	(13.403)
Number of new patients	17,736	17,735	4,176	4,274

Notes: Mean values are taken over per patient values. The standard deviations are in parentheses. The table includes only those patients who have their first warfarin prescription either during the year immediately before or during the year immediately after the adoption of e-prescribing. The time of the patient's first warfarin prescription is defined as the first time a warfarin prescription is observed for the patient in the data. The urban/semi-urban and rural classification in the columns is from Statistics Finland.

Next, we proceed to analyze whether the decreasing probability of a harmful interaction originates solely from the decrease in the length of NSAID prescription. Any major decreases in the length should not only show up as a reduction at the extensive margin of the interacting prescription (our baseline results), but also as a reduction at the intensive margin (interaction time). Note that the length of NSAID prescriptions does not affect one-way interactions of prescribing NSAIDs on top of warfarin, which decreased after e-prescribing (Section VII.A).

Figure A23 plots the event study estimates for the number of interacting days of each interacting prescriptions. As the number of observations is quite small, the estimates are more imprecisely estimated, but show no clear evidence for a decrease in the outcome. Figure A24 shows the density of interaction time separately for the pre-reform period and the long-run post-reform period. Again, no discernible differences can be detected between the densities. In sum, the decrease in the probability of a harmful interaction is not solely explained by the decrease in the length of NSAID prescriptions.

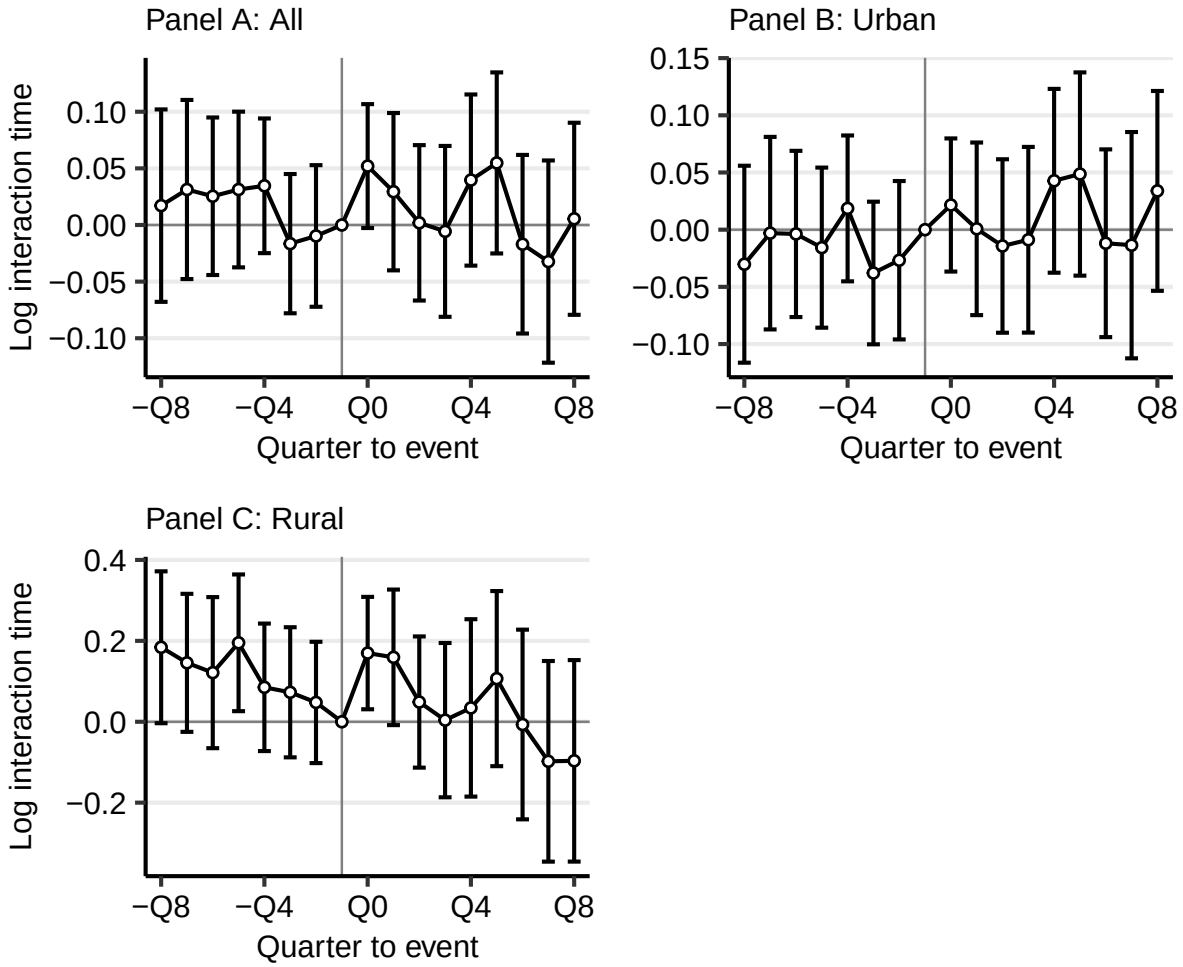

Figure A23
Duration of Warfarin-NSAID Interaction, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using the prescription-level data on interacting (wafarin and NSAID) prescriptions for warfarin patients. The outcome is the log number of days that the prescription interacts with another prescription. See Figure 6 for more information on the specification of the model.

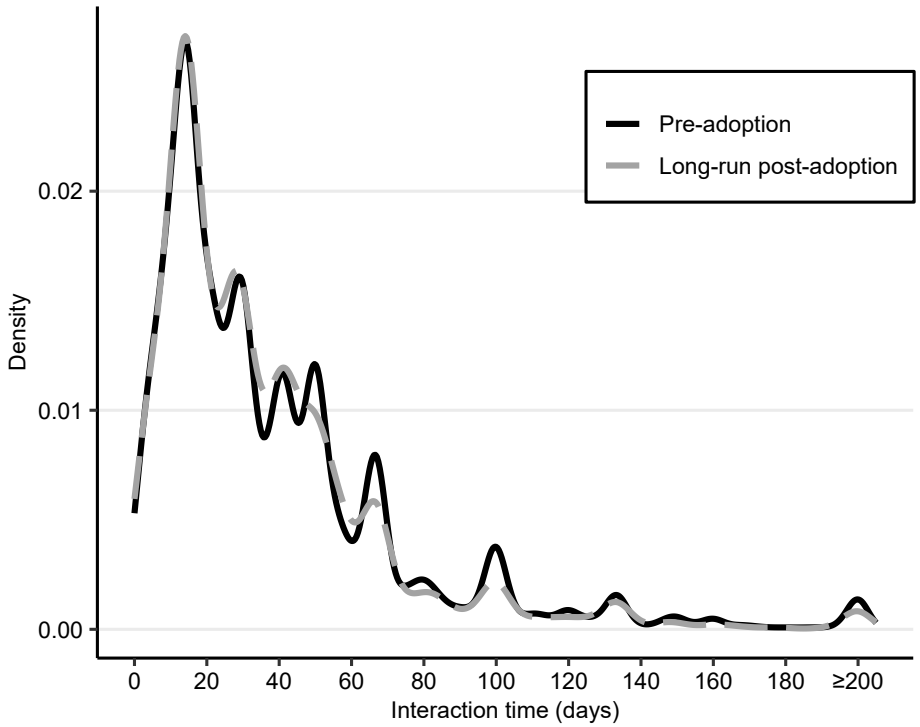

Figure A24
Density of Duration of Warfarin-NSAID Interaction

Notes: This figure plots the conditional density of the duration of each interacting (warfarin or NSAID) prescription, calculated in days, separately for the pre-adoption period (before 2010) and the long-run post-adoption period (at least one year after adoption). The length of warfarin and NSAID prescriptions is calculated using the number of defined daily doses of each prescription, where one day is assumed to be equal to one unit of daily dose.

B. Health outcome: Hospitalization for Gastrointestinal Bleeding

The focus of our paper is to study whether e-prescribing improved the coordination and quality of prescribing. However, it is also of interest to investigate whether these improvements translated into meaningful improvements in patient health. Because comprehensive analysis of various direct and indirect health effects is beyond the scope of our paper, we focus only on the most direct health outcome of the interaction of warfarin and NSAID: gastrointestinal bleeding.

The medical literature has documented that the simultaneous use of NSAIDs and warfarin significantly increases the risk of major bleeding complications, especially in the gastrointestinal tract (Battistella et al. 2005). Motivated by this evidence and the large decrease in such drug interactions in rural regions after e-prescribing (Section VII.A), we estimate the effects of e-prescribing on the probability of hospitalization for gastrointestinal bleeding (hemorrhage). We use aggregated patient-quarter-level balanced panel data for warfarin patients with at least one warfarin prescription during the observation period 2007–14. We find no evidence for a decrease in this bleeding outcome among warfarin patients after e-prescribing, even in rural regions (Figure A25 and Table A12).

There are several explanations for this finding. First, warfarin use by itself can cause excessive bleeding, especially when used in higher doses. We found that e-prescribing (digitization and easier renewal of prescriptions) increased the number of defined daily doses of warfarin prescriptions in rural regions. The increase in bleeding complications stemming from this increased size of warfarin prescriptions may counteract the complications stemming from fewer interacting prescriptions. In fact, Table A12 shows positive and statistically significant effects on the bleeding outcome.[7]

Second, the bleeding outcome may not be sensitive enough to capture the full short- and long-term positive effects of the decreased warfarin-NSAID interaction risk on latent health. Even though we study a well-established and widely used health outcome of warfarin-NSAID interactions in the medical literature (Battistella et al. 2005; Zapata et al. 2020), it is rare in the patient population (mean quarterly probability of 0.2 percent), and not all warfarin patients have an interacting prescription in a given quarter. Diagnosing bleeding complications is also complex, time-

[7] E-prescribing (improved information on a patient's prescriptions) may also improve diagnosing, thereby increasing their prevalence.

consuming, and may require several diagnostic tools (Kim et al. 2014). For example, a Finnish post-mortem study (Launiainen et al. 2010) shows that it is not uncommon that bleeding is diagnosed only after a patient's death.

The limitations of the data may also be relevant for finding no reduction in the probability of bleeding complications after e-prescribing for two reasons. First, we cannot completely rule out the potential role of the over-the-counter (OTC) market for NSAIDs. It is possible that substitution of prescription NSAIDs with OTC alternatives contributes to the health effect of e-prescribing, although physicians who stopped prescribing NSAIDs might have instructed their patients not to use or buy them OTC. Our prescription-level data do not permit us to study changes in the use of NSAIDs in the OTC market, but based on the aggregate consumption statistics for a commonly used NSAID, ibuprofen (Fimea and Kela 2015), use of this drug did not change much after municipalities started to adopt e-prescribing (years 2010-2014). Second, our data do not record information on the actual use of medications or whether patients are taking interacting medications (warfarin and NSAIDs) at the same time. This applies to nearly all administrative data from non-hospital settings.

Nonetheless, we find that the probability of hospitalization for gastrointestinal bleeding is 30 percent higher for patients with an interacting prescription for warfarin and NSAIDs compared to those with a warfarin prescription alone in a given quarter (Table A13), supporting the role of interacting prescriptions contributing to bleeding. In addition, as presented in Section VII.A, e-prescribing reduced the interaction probability by approximately 35 percent in rural regions. Based on these two estimates, we roughly approximate that the e-prescribing-induced decrease in drug interaction reduced the bleeding outcome by approximately $100 \times (0.3 \times 0.35) \approx 11$ percent.[8] Compared with the DiD estimate of the overall effect of e-prescribing on the bleeding outcome in rural regions (Table A12), this complementary back-of-the-envelope calculation yields a larger and more explicit estimate of the potential effects of e-prescribing in reducing the bleeding outcome through reduced drug interactions.

[8]In a meta-analysis (Zapata et al. 2020), the drug interaction increases gastrointestinal bleeding by 98 percent, but variation across and within study settings is large. This estimate implies even a larger reduction ($100 \times (0.98 \times 0.35) \approx 34$ percent) in the bleeding outcome as a result e-prescribing-induced decrease in the drug interaction than our raw data estimate of 30 percent.

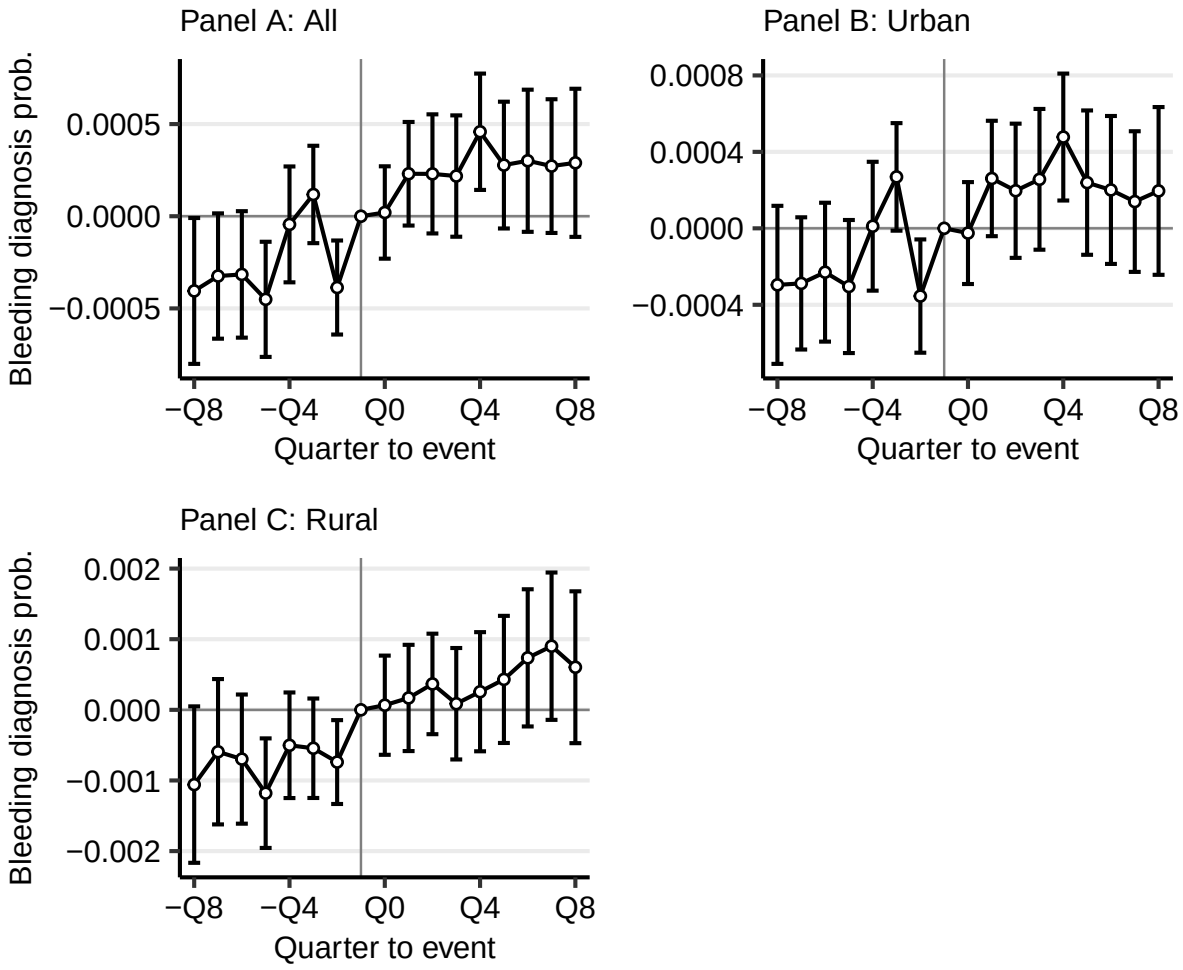

Figure A25

Probability of Hemorrhage (Bleeding) Diagnosis, by Municipality Group

Notes: These figures plot the coefficient estimates from an event study framework using patient-quarter-level balanced data on warfarin patients with at least one warfarin prescription during the observation period 2007–14. The outcome is a dummy variable that equals one if the patient has a hospital admission for gastrointestinal hemorrhage (bleeding) in a given period. The controls include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A12

Effects of E-prescribing on Hospitalization for Gastrointestinal Bleeding

	All municipalities	Urban	Rural
	(1)	(2)	(3)
Short-run	0.0003***	0.0002**	0.0005*
	(0.0001)	(0.0001)	(0.0003)
Long-run	0.0004***	0.0003**	0.0007**
	(0.0001)	(0.0001)	(0.0003)
Mean outcome	0.0020	0.0020	0.0021
Observations	7,361,632	5,920,658	1,440,974

Notes: This table reports the coefficient estimates from difference-in-differences regressions using patient-quarter-level balanced data for warfarin patients with at least one warfarin prescription during the observation period 2007–14. The outcome is a dummy variable that equals one if the patient has a hospital admission for gastrointestinal hemorrhage (bleeding) a given period. All regressions include municipality fixed effects, time fixed effects, age and age squared. The urban/semi-urban and rural classification in the columns is from Statistics Finland. The standard errors are clustered at the municipality level.

Table A13

Drug Interaction and Risk of Hospitalization for Gastrointestinal Bleeding at the Quarterly Level

	Warfarin only (1)	NSAID only (2)	Warfarin and NSAID interaction (3)
Mean outcome	0.0027	0.0019	0.0035
	(0.0001)	(0.0001)	(0.0002)
Observations	990,447	534,059	66,120

Notes: This table shows the means of the health outcome for patients who have a warfarin prescription only (Column 1), a NSAID prescription only (Column 2), and interacting prescriptions of both of these (Column 3) in a given quarter using the prescription-level data on warfarin patients combined with information on the timing of the bleeding outcome. The outcome is a dummy variable that equals one if the patient has a hospital admission for gastrointestinal hemorrhage (bleeding) in that quarter. The standard errors are shown in parentheses.

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