

Online Appendix

A. Estimating profitability of on-going loans

For the ongoing loans, we only observe the realized payments and the occurrence of default through the end of our sample period. Therefore, we estimate the expected profit using the probability of future default events, the likely recovery in case of default, and the projected future payments. Our profit estimate is:

$$\begin{aligned}
 Profit = \sum_d q_d \left[\sum_{i=1}^{d-1} PV(payment_{s_i}) + PV(Recovery_d | Default_d) \right] \\
 + (1 - \sum_d q_d) PV(all\ payments) - Initial\ investment \quad (6)
 \end{aligned}$$

where q_d is the default probability in month d estimated from the uncensored loans in the data. The first term sums the expected present value of the cash flows under the scenario that the loan defaults in month d . The second term represents the scenario in which the loan completes without default, which occurs with probability $1 - \sum_d q_d$.

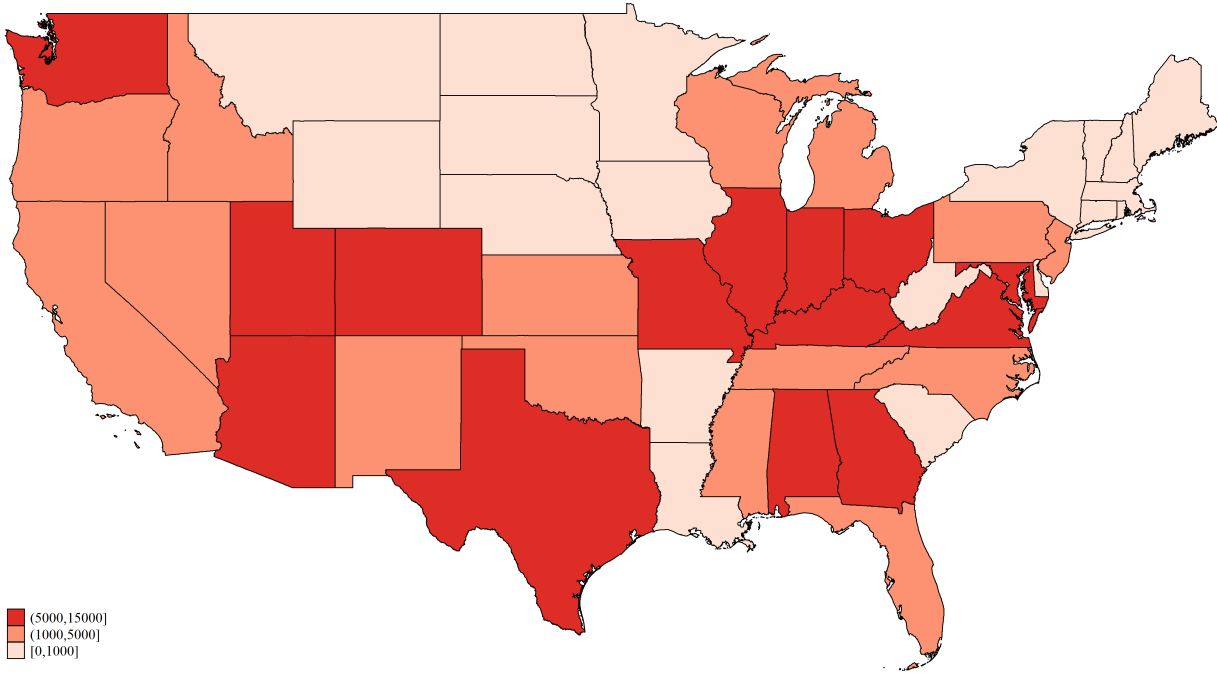
To estimate the the default probability, q_d , we use multiple supervised machine learning algorithms to train a credit model using more than 15 years of historical loan data prior to the initiation of the experiment. We use three types of models (logistic regression, random forest, and neural network) as well as a stacked ensemble model that combines the three. We include all potential default predictors available, including the credit score, DTI, LTV, prior bankruptcy, loan amount, homeownership, a dealership identifier, macroeconomics variables (such as the risk-free rate), the U.S. corporate BBB spread, and vehicle information such as make, model, mileage, and age. We train our models using 70% of the sample and test the model using a 30% test sample. The stacked model yields the best out-of-sample accuracy based on both the F1-score (0.68) and the AUC (Area Under the Curve) of ROC (Receiver Operating Characteristics) curve (0.71). We then use the stacked model to predict the default rate of the ongoing loans. This yields the aggregate default rate of each loan during its lifetime. To estimate the default rate for each month of a loan's life, we then project the aggregate default rate on the default trajectory estimated from the uncensored loans using a polynomial regression of order 5 as shown in Figure A.8. This yields the default likelihood of each loan for each month, q_d .⁴⁴

⁴⁴ Figure A.8 depicts the average predicted as well as the actual default rate in each period for the sample of loans in the experiment. The likelihood of default is low initially but rises quickly until approximately 24 months after loan origination, at which point it falls until the end of the loan term.

Next, we estimate the recovery in the case of default. We calculate the recovery amount as a percentage of gross default for all completed loans that default and estimate a regression of the percentage recovery on loan characteristics, vehicle characteristics, dealership, age of the loan, and all other variables used in predicting the default rate as discussed above. We then generate the expected recovery percentage for all the ongoing loans as a function of the age of the loan.

Finally, we calculate the expected percentage profit as the sum of the estimated cash flows divided by initial investment, similar to Equation (2) for completed loans.

Figure A.1 Geographic distribution of loans.



This map presents the geographic distribution of loans originated after 2012.

Figure A.2 Lender A's Underwriter Guideline.

Auto Financing Guidelines**Lender Requirements:**

Lender Name: 
 Type: Non Prime to Prime Auto Loans

Minimum FICO: Generally 550 (can go as low as 525 depending on situation)
 Minimum Age: 19
 Minimum Residence: 6 Months or 2 years in Area
 Minimum Employment: 12 Months History
 Minimum Income: \$1900
 Max DTI (gross/net): 50%
 Bankruptcy Exclusion: Re-established/Discharged
 Repossessions: 1 year or older

Deal Parameters:

Max Advance to Dealer: 125% of NADA Clean Retail
 Dealer Discount: Discount Fee may apply
 Down Payment: 0-20%
 Amount Financed: \$5,000 to \$100,000
 Term Range: 24-72 Months
 Rate Range: 3.99% to State Max depending on credit
 Finance Sales Tax: Yes
 Finance Gap: Max sale price \$800
 Finance Warranty: \$2500 max
 12 month 12,000 miles minimum coverage
 If PAF warranty isn't sold, \$100 fee will be deducted from advance
 Dealer Compensation (fee/reserve): N/A
 Processing Fee: TBD

Collateral Requirements:

New and/or Used Autos: Both acceptable
 Max Collateral Age: 2006 and newer
 Max Mileage: 100,000 (exceptions considered)
 Ineligible Vehicles: Salvage titles/buybacks not acceptable
 Value Collateral: NADA Clean Retail +/- Mileage +/- Options

Possible Stip Requirements:

Proof of Income Telephone/Electric Bill
 Proof of Residence Valid Driver's License
 References Proof of Insurance

**Figure A.3 Lender B's Underwriter Guideline.
 Standard Program Guidelines**

The Standard Program is ██████'s most popular program. Dealers rely on this program as the backbone of their sub-prime finance business. Customers with credit score 0-599 fall into the Standard Program tier. Benefits include:

- On-the-spot approval
- No minimum credit score
- No minimum amount financed
- No minimum income
- No minimum job time
- No minimum residence time
- Hard-to-prove incomes accepted
- Previous repossessions – no problem!
- No maximum vehicle age
- Bankruptcies OK (see BK Policy)
- No maximum vehicle mileage

Program Requirements

Credit Score:	599 & Below
PTI:	
Bureau Time:	No Min
Good Trades:	
Max Term:	42-72
Rates:	Up to max state usury
Down Payment:	10%
Max LTV:	140%

Min Discount:	\$75
Vehicle Age:	No Max

Stipulation Requirements

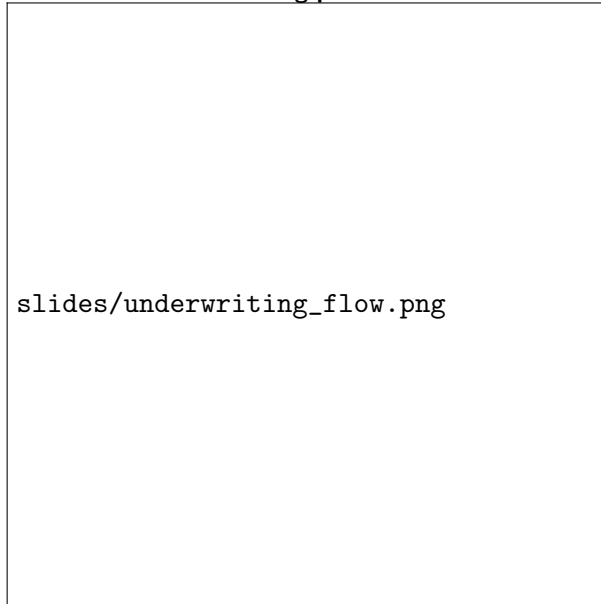
- | | |
|---------------------------------------|----------------------------|
| • Proof of Income | • 10 References |
| • Proof of Insurance | • Proof of Residence |
| • Driver License | • Landline/Cell Phone Bill |
| • Completed/Signed Credit Application | |

Figure A.4 Lender B's Guideline Details.**AAA Guidelines**

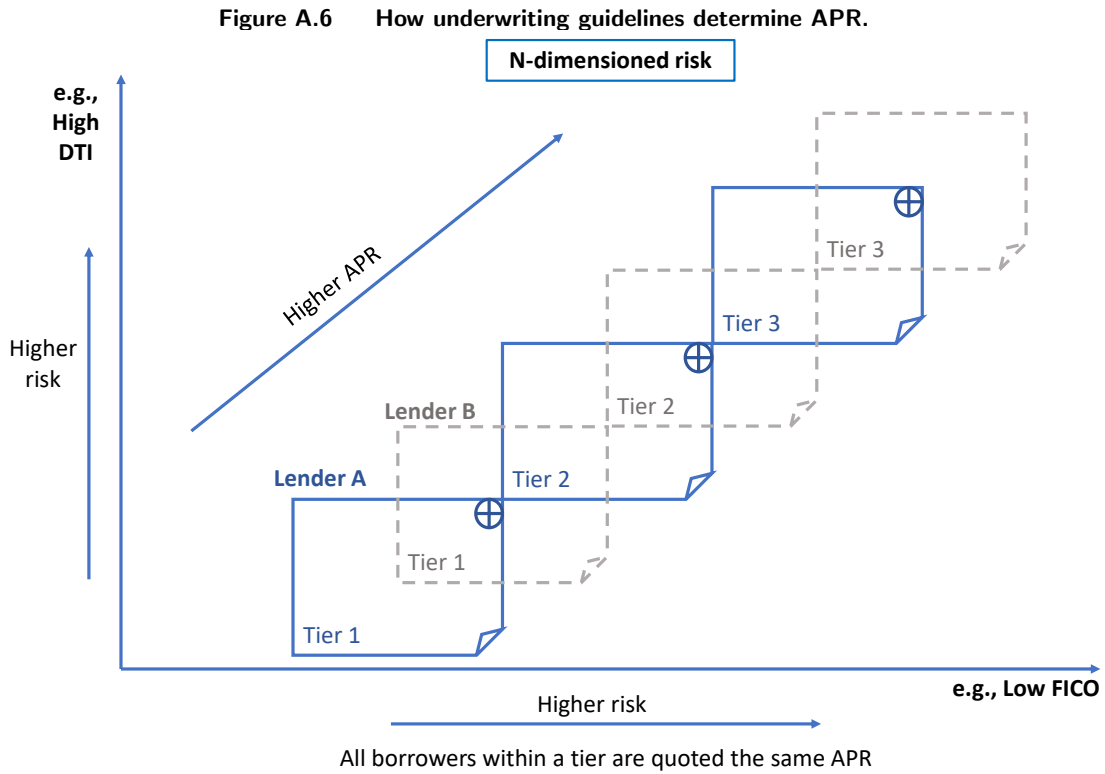
'AAA' any Titanium, Platinum, Gold or Standard program deal and receive lower APRs and dealer discounts. AAA deals must be structured to meet the deal requirements listed below. 'AAA' deals are available on vehicles of any age and mileage. Dealers may add up to 2% participation with no chargebacks (Gold, Platinum, and Titanium only).

Credit Score Range	Tier	Min. Payment	Min. Down Payment	Max LTV	A.P.R.	Discount
780+	1	\$300	10%	110%	5.99%	\$250
	2	\$300	10%	120%	7.99%	\$450
	3	\$300	10%	125%	9.99%	\$500
725-779	1	\$300	20%	100%	7.99%	\$400
	2	\$300	15%	110%	9.99%	\$600
	3	\$300	10%	115%	11.99%	\$700
680-724	1	\$275	25%	90%	9.99%	\$500
	2	\$275	15%	100%	11.99%	\$700
	3	\$275	10%	105%	13.99%	\$800
625-679	1	\$275	30%	80%	12.99%	\$700
	2	\$275	20%	90%	14.99%	\$800
	3	\$275	15%	95%	15.99%	\$900
575-624	1	\$250	35%	75%	15.99%	\$800
	2	\$250	25%	80%	16.99%	\$900
	3	\$250	20%	85%	18.99%	\$1,000
525-574	1	\$250	40%	65%	22.99%	\$1,250
	2	\$250	40%	70%	22.99%	\$1,500
	3	\$250	40%	75%	22.99%	\$1,750
300-524	1	\$250	45%	60%	24.99%	\$1,500
	2	\$250	45%	65%	24.99%	\$1,750
	3	\$250	45%	70%	24.99%	\$2,000
0	1	\$250	35%	75%	15.99%	\$800
	2	\$250	30%	85%	16.99%	\$900
	3	\$250	25%	90%	18.99%	\$1,000
Default	1	\$250	35%	60%	24.99%	\$1,500
	2	\$250	30%	65%	24.99%	\$1,750
	3	\$250	25%	70%	24.99%	\$2,000

Figure A.5 Difference in underwriting process between humans and machine.

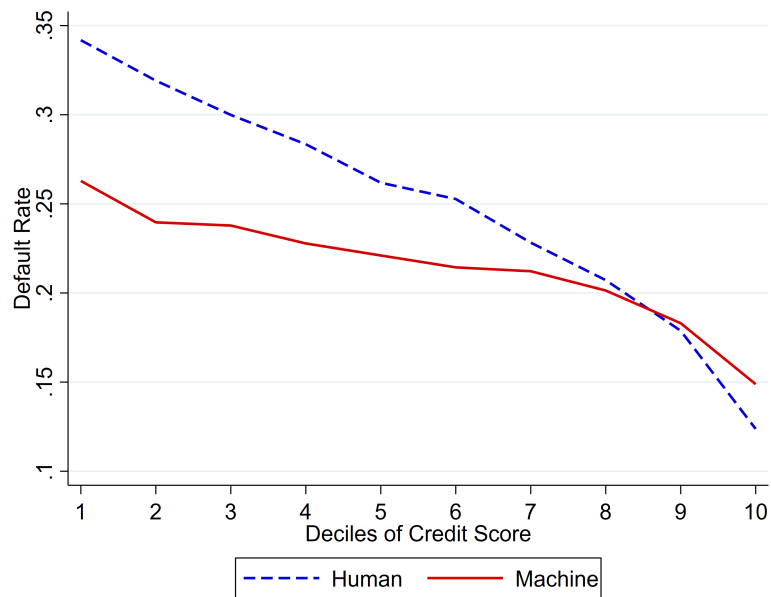


This figure illustrates the difference in the underwriting process between humans and the machine. To simplify the interpretation of many loan risk factors, the lender provides guidelines to underwriters on how to value risk factors (such as borrower's credit score and income) to price loans. Human underwriters use these guidelines to assign loans to risk tiers and set interest rates appropriate to the tiers. In contrast, algorithmic underwriting (i.e., the machine) uses risk factors as inputs to an equation, which was generated from coefficient estimates in a regression to evaluate the risk of default.

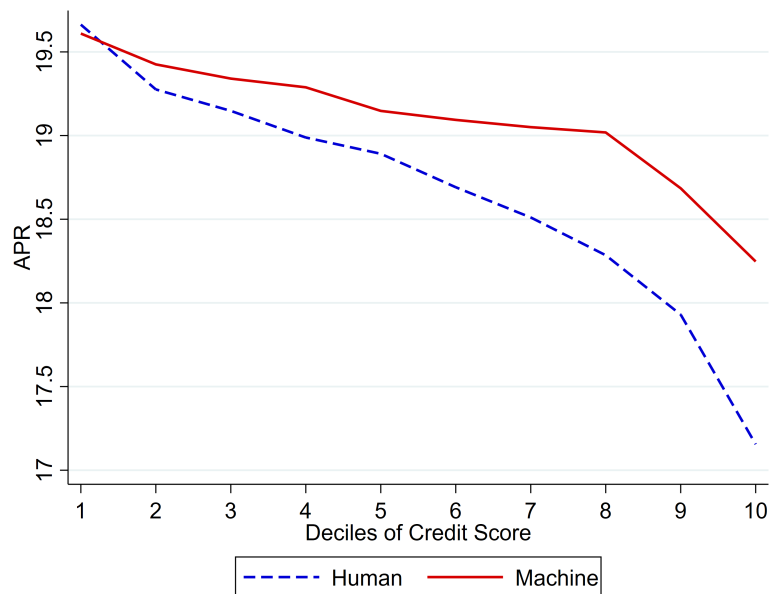


This figure illustrates how a mapping of borrower risk factors into tiers impacts loan interest rate. A loan just inside the bounds for tier 1 can be priced at tier 1 interest rates, while a loan just above the tier 1 threshold has to be priced at tier 2 interest rates. Underwriters at Lender A that submit a bid just below the Lender A threshold are likely to offer lower interest rates, compared to tier 1 pricing for Lender B.

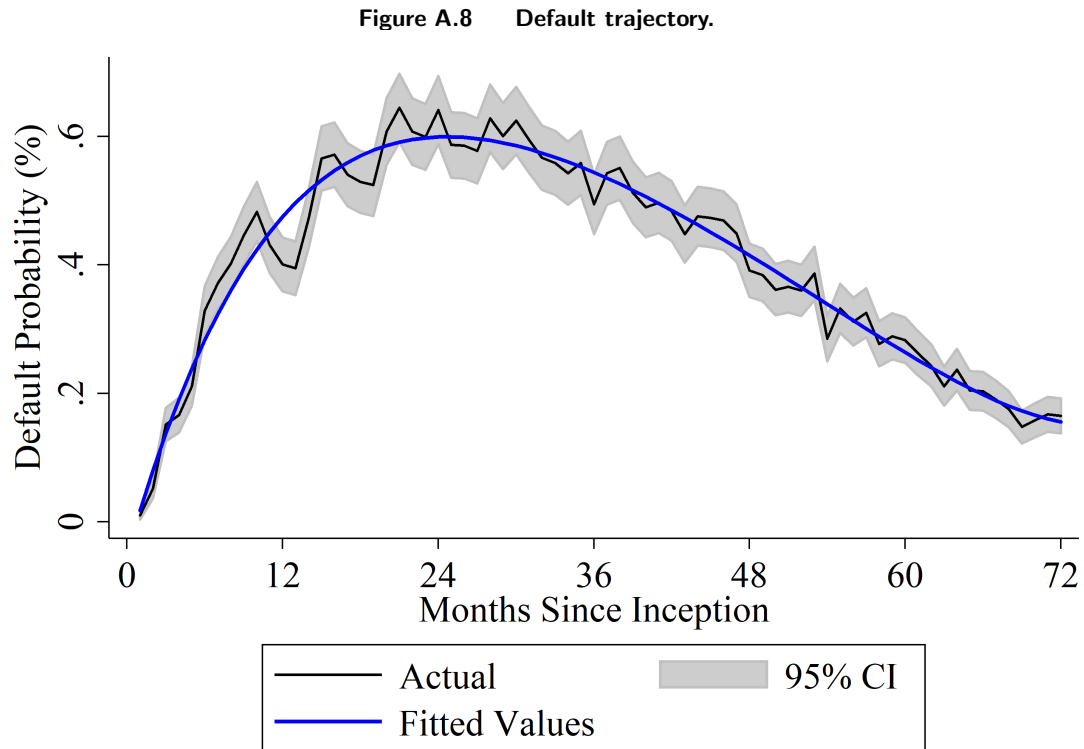
Figure A.7 Loan characteristics across deciles of credit score.
(a) Default rate



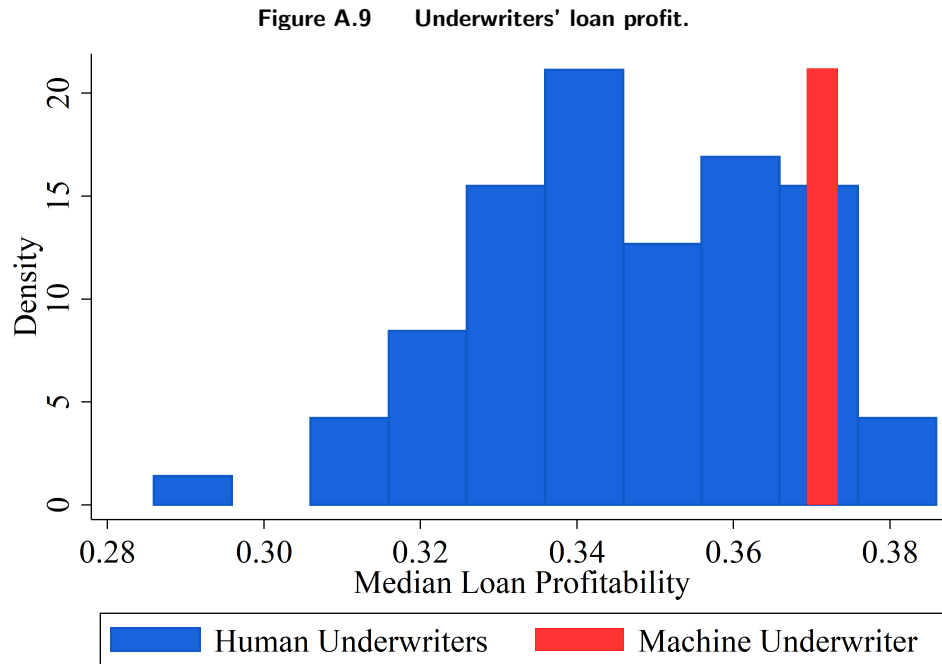
(b) APR (%)



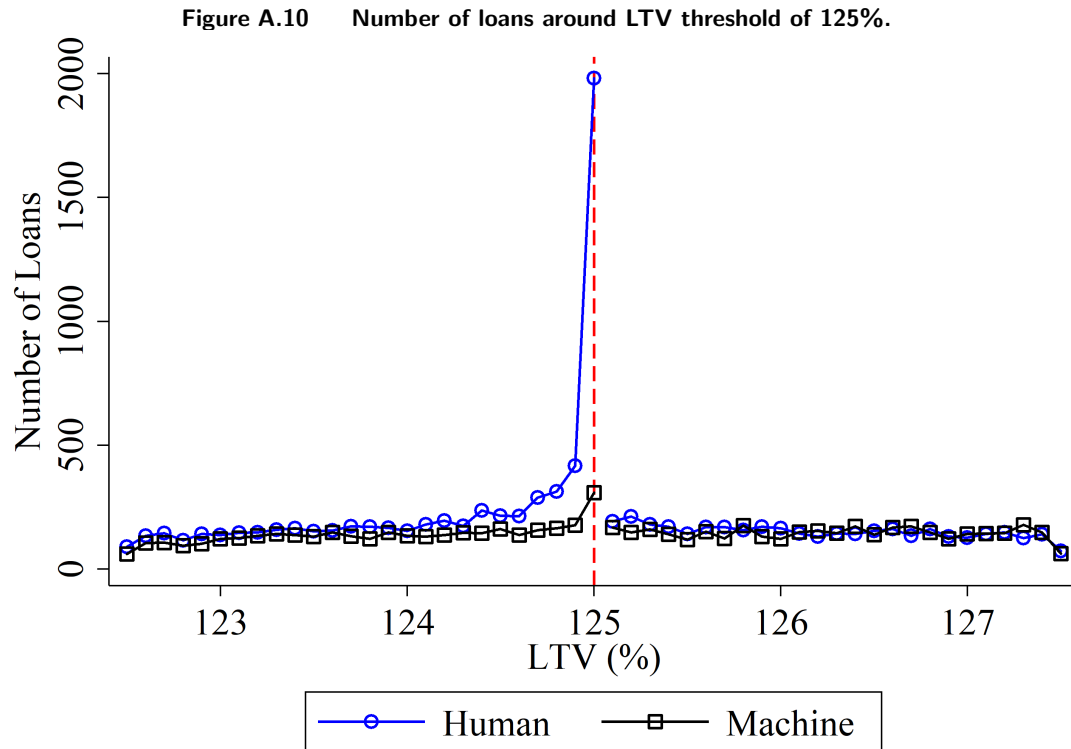
This figure divides all the loans in our experiment into deciles of credit score each month, then plots the average default rate, and APR of loans originated by human and machine underwriters for each decile. The blue dashed lines summarize characteristics of loans underwritten by human, and the red solid lines represent loans underwritten by the machine. Panel A shows the average default rate. Panel B shows the average APR.



For each month since origination, this figure contrasts the realized default rates against the predicted default rates generated by a polynomial regression model of order 5 based on historical data starting in January 1997. The black line represents the actual default rates, while the blue line represents the model prediction.

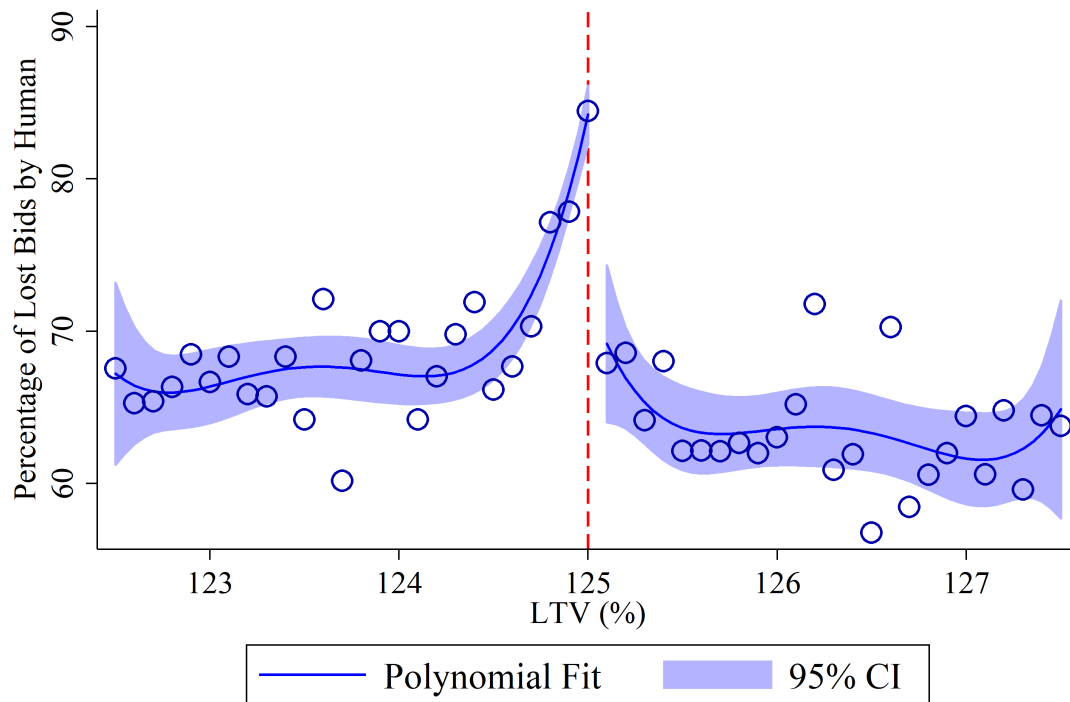


This figure shows the distribution of median loan profit of the machine underwriter and of human underwriters. We exclude underwriters who underwrote fewer than 50 loans in our sample period. The machine underwriter's median loan profit is represented by the red bar. The human underwriters' median loan profits are represented by the blue bars.



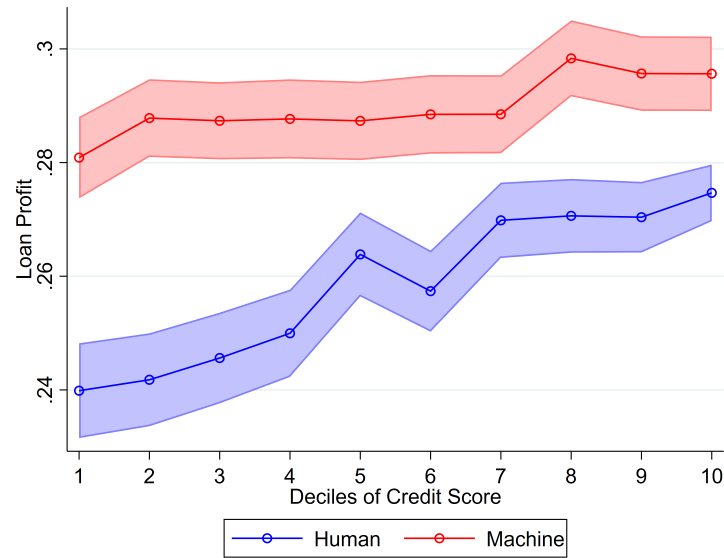
This figure presents the number of loans underwritten by humans and the machine around the LTV ratio of 122.5% to 127.5%. The vertical dashed line represents the LTV threshold of 125%. The hollow blue circles show the number of loans underwritten by humans for LTV bins of 0.1%. The hollow black squares show the number of loans underwritten by the machine for LTV bins of 0.1%.

Figure A.11 Distribution of applications around LTV threshold of 125%.

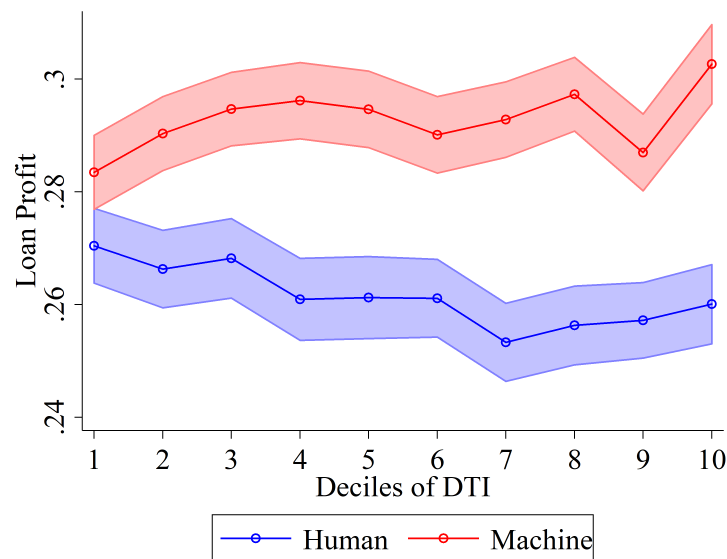


This figure presents the percentage of lost bids by human underwriters relative to the total lost bids in our sample. Lost bids are the bids that were submitted to the loan auctions for approved loan applications, but did not win the auction and did not result in a loan. The sample spans loan-to-value ratio (LTV) from 122.5% to 127.5%. The vertical dashed line represents the loan-to-value threshold of 125%. The hollow blue circles show the percentage of lost bids by humans for LTV bins of 0.1%. The blue lines show the polynomial fit of the average percentage values at corresponding LTV values, and the surrounding blue areas show the 95% confidence interval.

Figure A.12 Loan profit and deciles of credit score and debt-to-income ratio.
(a) Credit Score

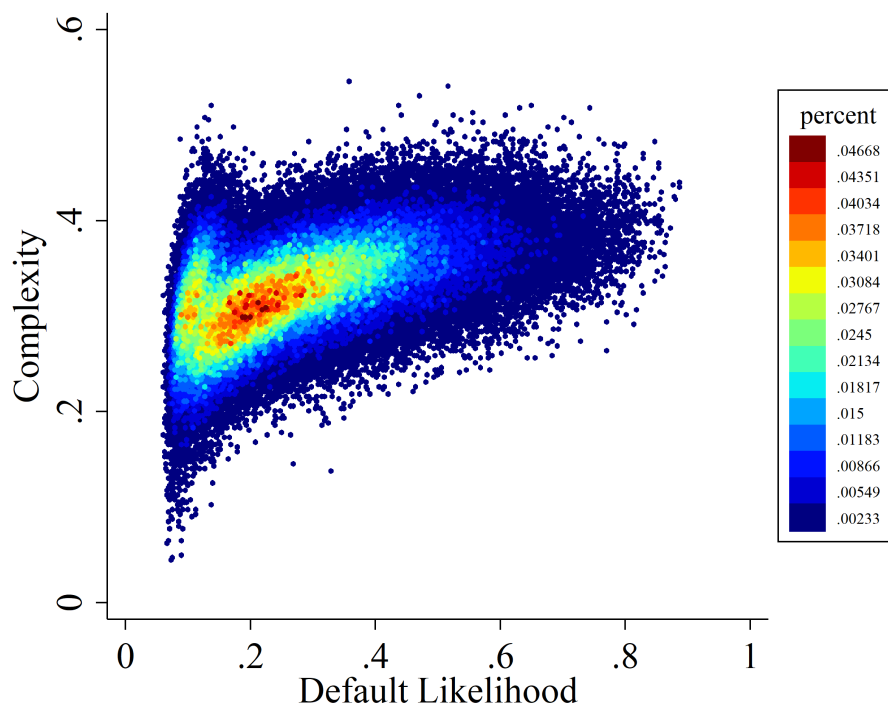


(b) Debt-to-income Ratio

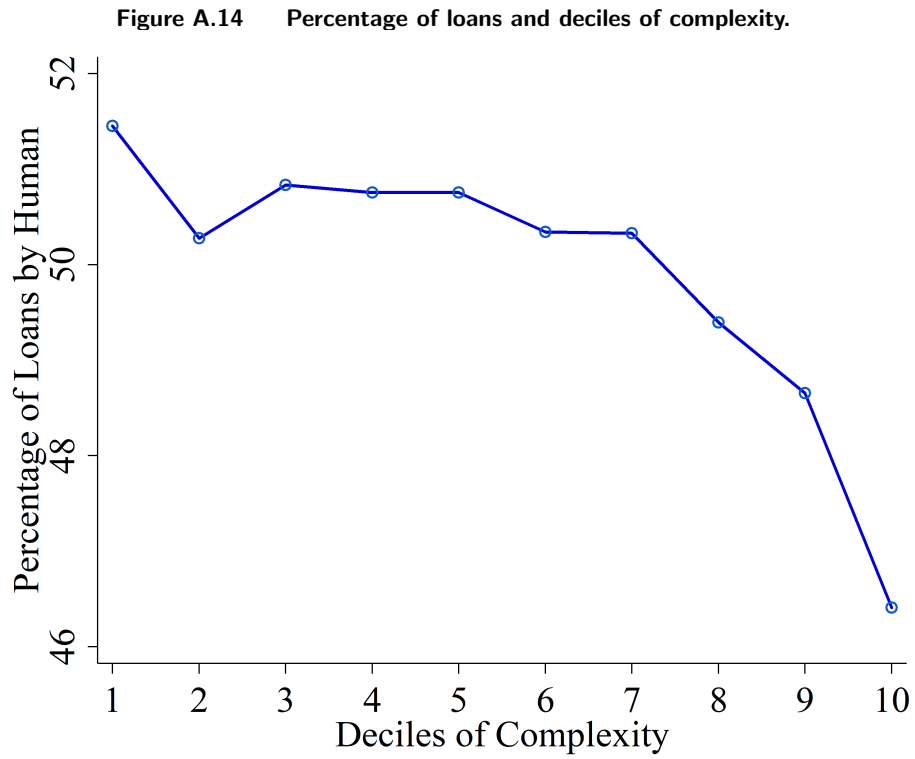


This figure shows the loan profits of machine- and human-underwritten loans across borrower characteristics. The blue (red) lines show the average profit of loans underwritten by humans (machine). The surrounding blue (red) areas show the 95% confidence interval. Panel A shows average loan profits across deciles of credit score. Panel B shows average loan profits across deciles of debt-to-income (DTI). A high DTI means lower relative income

Figure A.13 The relationship between complexity and default likelihood.

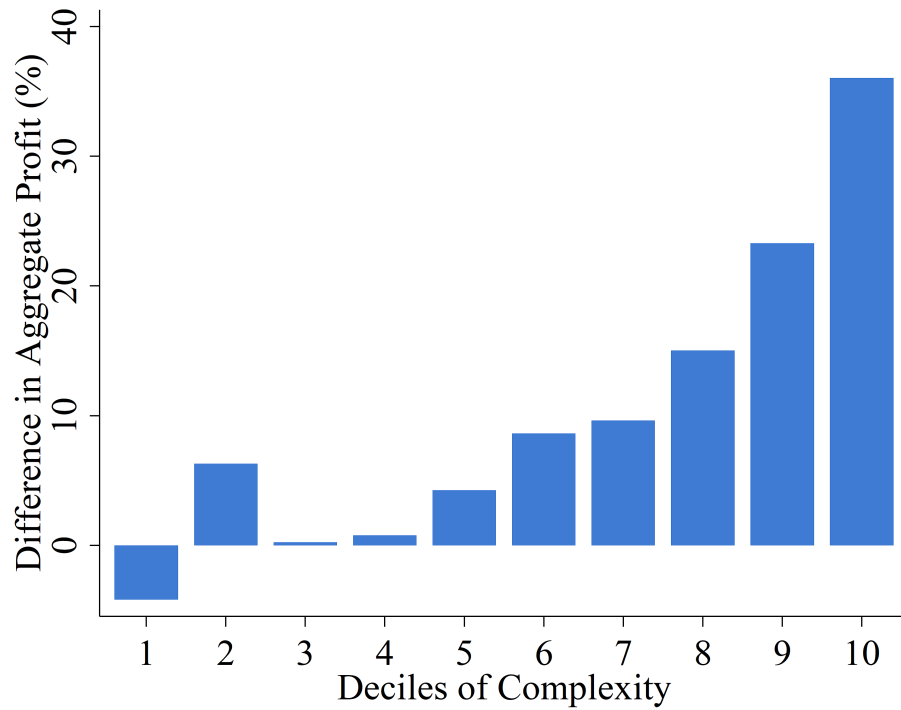


This figure shows the heatmap of the relationship between loan complexity and likelihood of default. The complexity measure is constructed using out-of-sample estimates of the forecast errors conditional on loan, borrower, and vehicle characteristics from more than 15 years of historical loan data before the beginning of the experiment. The details are described in Section 5.2.2



This figure divides all the loans in our experiment into deciles of complexity each month, then plots the percentage of loans originated by human underwriters for each decile. The complexity measure is constructed as described in Section 5.2.2.

Figure A.15 Difference in dollar profit by decile of complexity as a percentage of aggregate profit difference.



This figure divides all the loans in our experiment into deciles of complexity each month, then calculates the difference in aggregate dollar profit generated by machine- and human-underwritten loans for each decile, and reports the results as a percentage of aggregate dollar profit difference between the machine- and human-underwritten portfolio. The complexity measure is constructed as described in Section 5.2.2.

Table A.1 Difference in prepayment risk of human- and machine-underwritten loans.

	(1)	(2)	(3)
Sample:	Uncensored	Censored	All
Machine	0.008 (0.008)	0.004 (0.004)	0.005 (0.004)
Constant	0.548*** (0.007)	0.310*** (0.005)	0.337*** (0.005)
Observations	18899	120023	141023
Dep Var Mean	0.552	0.312	0.339
Adjusted R^2	0.002	0.064	0.082

This table reports estimates from panel regressions of prepayment rate on whether the loan is underwritten by the machine. The dependent variable is an indicator equal to one if the loan is prepaid, and zero otherwise. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. “Uncensored” loans are those whose original terms do not extend beyond the end of our sample period. “Censored” loans are those whose original terms extend beyond our sample period. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.2 Difference in loan profit, interest rate, and default rate of human- and machine-underwritten loans, including loans originated in the last 11 months of the sample period.

Panel A: Profit ratio				
Sample:	(1) Uncensored	(2) Completed	(3) Censored	(4) All
Machine	0.025*** (0.006)	0.027*** (0.004)	0.027*** (0.003)	0.026*** (0.002)
Year-Month FE	YES	YES	YES	YES
Observations	18887	83258	140105	161091
Dep Var Mean	0.276	0.189	0.290	
Adjusted R^2	0.004	0.030	0.035	0.031

Panel B: APR (%)			
Sample:	(1) Uncensored	(2) Censored	(3) All
Machine	0.462*** (0.036)	0.458*** (0.038)	0.456*** (0.035)
Year-Month FE	YES	YES	YES
Observations	18899	140718	161718
Dep Var Mean	18.939	18.971	18.966
Adjusted R^2	0.041	0.056	0.050

Panel C: Default rate			
Sample:	(1) Uncensored	(2) Censored	(3) All
Machine	-0.017** (0.007)	-0.014*** (0.004)	-0.015*** (0.004)
Year-Month FE	YES	YES	YES
Observations	18899	140718	161718
Dep Var Mean	0.315	0.184	0.201
Adjusted R^2	0.003	0.084	0.081

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine. The loan-level profit ratio is equal to profit/initial investment. *APR* (%) is the contracted interest rate of a loan. Default rate is an indicator equal to one if the loan defaults and zero otherwise. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. “Uncensored” loans are those whose original terms do not extend beyond the end of our sample period. “Completed” loans are those that have been completed during our sample period. “Censored” loans are those whose original terms extend beyond our sample period. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.3 Difference in loan profit of human- and machine-underwritten loans, with controls.

Sample:	(1) Uncensored	(2) Completed	(3) Censored	(4) All
Machine	0.020*** (0.004)	0.024*** (0.003)	0.024*** (0.002)	0.024*** (0.002)
Loan-to-Value	-0.150*** (0.021)	-0.219*** (0.012)	-0.118*** (0.010)	-0.125*** (0.009)
Loan Amount	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)
Term (months)	0.002*** (0.000)	-0.000 (0.000)	0.003*** (0.000)	0.003*** (0.000)
Discount	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Credit Score	0.000*** (0.000)	0.001*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Homeowner Indicator	-0.005 (0.012)	0.008 (0.007)	0.002 (0.005)	0.001 (0.005)
Bankruptcy	0.027*** (0.005)	0.073*** (0.006)	0.031*** (0.003)	0.030*** (0.003)
Debt-to-Income Ratio	-0.081*** (0.021)	-0.008 (0.007)	-0.012 (0.011)	-0.011 (0.007)
New Car Indicator	-0.018* (0.010)	-0.044*** (0.007)	-0.019*** (0.005)	-0.020*** (0.005)
Car Age (years)	-0.007*** (0.002)	-0.011*** (0.001)	-0.005*** (0.001)	-0.006*** (0.001)
Year-Month FE	YES	YES	YES	YES
Dealer FE	YES	YES	YES	YES
Car Make FE	YES	YES	YES	YES
Car Model FE	YES	YES	YES	YES
Day of Week FE	YES	YES	YES	YES
Day of Month FE	YES	YES	YES	YES
Observations	17796	78806	113379	133629
Dep Var Mean	0.274	0.188	0.274	0.274
Adjusted R^2	0.046	0.097	0.065	0.062

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine. The dependent variable is the loan-level profit ratio (profit/initial investment). *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. “Uncensored” loans are those whose original terms do not extend beyond the end of our sample period. “Completed” loans are those that have been completed during our sample period. “Censored” loans are those whose original terms extend beyond our sample period. The regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.4 Difference in loan profit for loans without interest rate markup by dealers.

Panel A: Without controls				
Sample	(1) Uncensored	(2) Completed	(3) Censored	(4) All
Machine	0.033*** (0.009)	0.024*** (0.007)	0.029*** (0.005)	0.030*** (0.005)
Year-Month FE	YES	YES	YES	YES
Observations	7131	29447	40393	48312
Dep Var Mean	0.280	0.175	0.286	0.285
Adjusted R^2	0.006	0.042	0.034	0.030

Panel B: With controls				
Sample	(1) Uncensored	(2) Completed	(3) Censored	(4) All
Machine	0.028*** (0.007)	0.020*** (0.006)	0.025*** (0.004)	0.025*** (0.004)
Year-Month FE	YES	YES	YES	YES
Dealer FE	YES	YES	YES	YES
Car Make FE	YES	YES	YES	YES
Car Model FE	YES	YES	YES	YES
Controls	YES	YES	YES	YES
Observations	6440	27467	37626	45242
Dep Var Mean	0.276	0.174	0.281	0.281
Adjusted R^2	0.052	0.118	0.088	0.082

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine, for loans that have no interest rate markup by dealers. Panel A shows results without controls. Panel B's regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). The dependent variable is the loan-level profit ratio (profit/initial investment). *Machine* is an indicator equal to one if the loan is underwritten by the machine, and zero if the loan is underwritten by a human underwriter. "Uncensored" loans are those whose original terms do not extend beyond the end of our sample period. "Completed" loans are those that have been completed during our sample period. "Censored" loans are those whose original terms extend beyond our sample period. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.5 Difference in interest rates of human- and machine-underwritten loans, with controls.

Sample:	(1) Uncensored	(2) Censored	(3) All	(4) All
Machine	0.313*** (0.021)	0.284*** (0.023)	0.293*** (0.022)	0.442*** (0.036)
Loan-to-Value	1.056*** (0.099)	1.313*** (0.077)	1.260*** (0.070)	
Loan Amount	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)	
Term (months)	0.003 (0.004)	-0.025*** (0.004)	-0.014*** (0.003)	
Discount	0.002*** (0.000)	0.002*** (0.000)	0.002*** (0.000)	
Credit Score	-0.014*** (0.001)	-0.010*** (0.000)	-0.011*** (0.000)	
Homeowner Indicator	-0.409*** (0.056)	-0.264*** (0.027)	-0.286*** (0.025)	
Bankruptcy	-0.800*** (0.056)	-0.609*** (0.039)	-0.649*** (0.040)	
Debt-to-Income Ratio	0.055 (0.157)	-0.062 (0.055)	-0.054 (0.034)	
New Car Indicator	-0.026 (0.074)	0.100* (0.056)	0.076 (0.050)	
Car Age (years)	0.041*** (0.015)	0.088*** (0.010)	0.084*** (0.010)	
Year-Month FE	YES	YES	YES	YES
Dealer FE	YES	YES	YES	NO
Car Make FE	YES	YES	YES	NO
Car Model FE	YES	YES	YES	NO
Observations	17807	113863	134126	141023
Dep Var Mean	18.925	18.859	18.869	18.893
Adjusted R^2	0.423	0.463	0.450	0.045

This table reports estimates from panel regressions of interest rate on whether the loan is underwritten by the machine. The dependent variable is the contracted interest rate of a loan (*APR* percent). *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. “Uncensored” loans are those whose original terms do not extend beyond the end of our sample period. “Censored” loans are those whose original terms extend beyond our sample period. The regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.6 Difference in default rates of human- and machine-underwritten loans, with controls.

Sample:	(1) Uncensored	(2) Censored	(3) All	(4) All
Machine	-0.024*** (0.005)	-0.021*** (0.004)	-0.021*** (0.003)	-0.016*** (0.004)
Loan-to-Value	0.231*** (0.025)	0.145*** (0.015)	0.162*** (0.013)	
Loan Amount	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	
Term (months)	0.003*** (0.001)	-0.001*** (0.000)	0.000 (0.000)	
Discount	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	
Credit Score	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	
Homeowner Indicator	-0.042* (0.022)	-0.038*** (0.007)	-0.040*** (0.007)	
Bankruptcy	-0.085*** (0.012)	-0.059*** (0.005)	-0.063*** (0.004)	
Debt-to-Income Ratio	0.225*** (0.027)	0.035* (0.019)	0.032** (0.012)	
New Car Indicator	0.015 (0.016)	0.025*** (0.009)	0.025*** (0.008)	
Car Age (years)	0.011*** (0.003)	0.010*** (0.002)	0.011*** (0.001)	
Year-Month FE	YES	YES	YES	YES
Dealer FE	YES	YES	YES	NO
Car Make FE	YES	YES	YES	NO
Car Model FE	YES	YES	YES	NO
Observations	17807	113863	134126	141023
Dep Var Mean	0.319	0.217	0.232	0.229
Adjusted R^2	0.093	0.106	0.109	0.050

This table reports estimates from panel regressions of default rate on whether the loan is underwritten by the machine. The dependent variable is an indicator equal to one if the loan defaults and zero otherwise. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. “Uncensored” loans are those whose original terms do not extend beyond the end of our sample period. “Censored” loans are those whose original terms extend beyond our sample period. The regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.7 Loan interest rate and default around LTV ratio of 125%.

Panel A: Early Default Probability					
	(1)	(2)	(3)	(4)	(5)
Dep Var:	DEF^{12}	DEF^{18}	DEF^{24}	DEF^{30}	DEF^{36}
Machine	0.001 (0.003)	0.005 (0.005)	-0.003 (0.006)	-0.007 (0.008)	-0.012 (0.009)
LTV125	0.003 (0.004)	0.011* (0.006)	0.029*** (0.007)	0.056*** (0.009)	0.065*** (0.011)
Machine \times LTV125	-0.004 (0.008)	-0.016 (0.011)	-0.043*** (0.013)	-0.060*** (0.014)	-0.080*** (0.017)
Year-Month FE	YES	YES	YES	YES	YES
Observations	12091	12091	12091	12091	12091
Dep Var Mean	0.035	0.071	0.121	0.171	0.213
Adjusted R^2	0.000	0.000	0.002	0.005	0.006

Panel B: APR (%)				
	(1)	(2)	(3)	
Sample	LTV:124-126	LTV:122.5-127.5	LTV:120-130	
Machine	0.167** (0.065)	0.193*** (0.044)	0.218*** (0.034)	
Below Cutoff	-0.122 (0.079)	-0.032 (0.056)	-0.053 (0.051)	
Machine \times Below Cutoff	0.274*** (0.087)	0.209*** (0.060)	0.140*** (0.043)	
Year-Month FE	YES	YES	YES	
Dealer FE	YES	YES	YES	
Car Make FE	YES	YES	YES	
Car Model FE	YES	YES	YES	
Controls	YES	YES	YES	
Observations	8407	16946	30135	
Dep Var Mean	18.944	18.882	18.867	
Adjusted R^2	0.390	0.402	0.406	

This table reports the effect of machine underwriting around the loan-to-value (LTV) ratio of 125%. The sample in Panel A includes loans with LTV ratio ranging from 122.5% to 127.5%. LTV125 is an indicator equal to one if the loan's LTV ratio is between 124.5% and 125%, and zero otherwise. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. *Below Cutoff* is an indicator equal to one if the loan's LTV ratio is less than or equal to 125% and zero if LTV ratio is greater than 125%. The dependent variables in Panel A are the same early default probabilities used in Panel B of Table 4. The dependent variable in Panel B is the loan's interest rate. The regressions in Panel B control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.8 Inflation of car book value around LTV ratio of 125%.

Panel A: Hedonic regression	
	Car Book Value
New Car Indicator	4221.199*** (131.868)
Car Age (years)	-892.782*** (14.909)
Car Mileage	-0.055*** (0.002)
Remaining Warranty (years)	-46.148*** (11.911)
Remaining Warranty (mileage)	0.002 (0.002)
Year-Month FE	YES
Dealer FE	YES
Car Make FE	YES
Car Model FE	YES
Observations	134145
Dep Var Mean	13779
Adjusted R^2	0.820

Panel B: Book value inflation around LTV cut off of 125%

	Residuals
Machine	0.006*** (0.002)
LTV125	0.002 (0.002)
Machine \times LTV125	-0.003 (0.004)
APR	0.002*** (0.000)
Loan Amount	0.000*** (0.000)
Term (months)	0.000 (0.000)
Credit Score	0.000 (0.000)
Debt-to-Income Ratio	-0.006 (0.008)
Discount	-0.000 (0.000)
Loan-to-Value	-0.002*** (0.000)
Homeowner Indicator	0.004 (0.004)
Bankruptcy	-0.004** (0.002)
New Car Indicator	-0.088*** (0.005)
Car Age (years)	0.010*** (0.001)
Year-Month FE	YES
Observations	17569
Dep Var Mean	0.005
Adjusted R^2	0.140

Panel A of this table reports estimates from the hedonic regression of car book value on other car characteristics. Panel B reports the regression of the book value residual (from the hedonic regression in Panel A) on whether the underwriter is human, an indicator for LTV value of just below 125%, and their interaction. LTV125 is an indicator equal to one if the loan's LTV ratio is between 124.5% and 125% and zero otherwise. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. The regression in Column (2) of Panel B controls for loan characteristics (APR, loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.9 Difference in APR residuals.

Panel A: Without controls				
	(1)	(2)	(3)	(4)
Sample:	Uncensored	Completed	Censored	All
Machine	-0.064*** (0.023)	-0.051*** (0.011)	-0.063*** (0.011)	-0.063*** (0.010)
Year-Month FE	YES	YES	YES	YES
Observations	18127	79062	113977	134126
Dep Var Mean	0.020	0.019	-0.004	-0.000
Adjusted R^2	0.010	0.002	0.004	0.004
Panel B: With controls				
	(1)	(2)	(3)	(4)
Sample:	Uncensored	Completed	Censored	All
Machine	-0.056** (0.023)	-0.037*** (0.010)	-0.041*** (0.009)	-0.045*** (0.008)
Loan Amount	0.000 (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Term (months)	-0.005*** (0.002)	-0.011*** (0.001)	-0.016*** (0.002)	-0.012*** (0.001)
Credit Score	0.001*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.002*** (0.000)
Debt-to-Income Ratio	-0.158** (0.072)	0.015 (0.020)	0.013 (0.028)	0.003 (0.024)
Discount	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)
Loan-to-Value	-0.207*** (0.063)	-0.197*** (0.035)	-0.214*** (0.030)	-0.224*** (0.030)
Homeowner Indicator	-0.020 (0.020)	0.009 (0.016)	0.019 (0.016)	0.010 (0.014)
Bankruptcy	0.017 (0.027)	0.063*** (0.013)	0.092*** (0.014)	0.078*** (0.013)
New Car Indicator	-0.033 (0.031)	-0.013 (0.021)	-0.009 (0.024)	-0.012 (0.021)
Car Age (years)	0.007 (0.009)	0.022*** (0.004)	0.027*** (0.004)	0.026*** (0.003)
Year-Month FE	YES	YES	YES	YES
Dealer FE	YES	YES	YES	YES
Car Make FE	YES	YES	YES	YES
Car Model FE	YES	YES	YES	YES
Observations	17807	78806	113863	134126
Dep Var Mean	0.021	0.019	-0.004	-0.000
Adjusted R^2	0.084	0.080	0.098	0.093

This table report estimates from panel regressions of the APR residuals on whether the loan is underwritten by humans or the machine. The dependent variable is the standardized absolute value of the residual from a regression of APR on a full set of characteristics, including LTV, loan amount, loan term, discount, DTI, credit score, homeownership, prior bankruptcy, whether the vehicle is used or new, and vehicle age, as well as year-month, dealer, make, and model fixed effects. *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. Panel B controls for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.10 Difference in loan profit across borrower characteristics, with controls.

Dep Var:	(1) Loan Profit	(2) Loan Profit	(3) Loan Profit
Machine	0.014*** (0.002)	0.018*** (0.002)	0.018*** (0.002)
Low Credit Score	-0.038*** (0.003)		
Machine \times Low Credit Score	0.018*** (0.003)		
High DTI		-0.013*** (0.002)	
Machine \times High DTI		0.012*** (0.003)	
Low Credit Score-High DTI			-0.017*** (0.003)
Machine \times Low Credit Score-High DTI			0.024*** (0.004)
Year-Month FE	YES	YES	YES
Dealer FE	YES	YES	YES
Car Make FE	YES	YES	YES
Car Model FE	YES	YES	YES
Controls	YES	YES	YES
Observations	133629	133651	133629
Dep Var Mean	0.274	0.274	0.274
Adjusted R^2	0.061	0.062	0.063

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine, and on different risk characteristics of customers. The dependent variable is the loan-level profit ratio (profit/initial investment). *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. *Low Credit Score* is an indicator equal to one if the debtor's credit score is below the median credit score in the data, and zero otherwise. *High DTI* is an indicator equal to one if the debtor's DTI is above the median DTI, and zero otherwise. *Low Credit Score-High DTI* is an indicator equal to one if *Low Credit Score* and *High DTI* are both equal to one, and zero otherwise. The regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age, import dummy, luxury dummy). Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.11 Difference in loan profit across borrower characteristics, subsamples and quantile analysis.

Panel A: Difference in loan profit in subsamples			
Sample:	(1) Uncensored	(2) Completed	(3) Censored
Machine	0.016*** (0.006)	0.014*** (0.004)	0.020*** (0.003)
Low Credit Score-High DTI	-0.024*** (0.009)	-0.042*** (0.006)	-0.020*** (0.004)
Machine \times Low Credit Score-High DTI	0.030*** (0.010)	0.045*** (0.005)	0.023*** (0.004)
Year-Month FE	YES	YES	YES
Observations	18245	79417	113961
Dep Var Mean	0.275	0.189	0.274
Adjusted R^2	0.005	0.032	0.023

Panel B: Difference in loan profit across quartiles of credit score and DTI			
Dep Var:	(1) Loan Profit	(2) Loan Profit	
Machine=1	0.041*** (0.006)	0.013*** (0.003)	
Credit Score Quartiles=2	0.015*** (0.004)		
Credit Score Quartiles=3	0.025*** (0.005)		
Credit Score Quartiles=4	0.032*** (0.006)		
Machine=1 \times Credit Score Quartiles=2	-0.013** (0.005)		
Machine=1 \times Credit Score Quartiles=3	-0.020*** (0.005)		
Machine=1 \times Credit Score Quartiles=4	-0.022*** (0.006)		
DTI Quartiles=2			-0.004 (0.003)
DTI Quartiles=3			-0.009** (0.004)
DTI Quartiles=4			-0.011** (0.004)
Machine=1 \times DTI Quartiles=2			0.013*** (0.004)
Machine=1 \times DTI Quartiles=3			0.017*** (0.005)
Machine=1 \times DTI Quartiles=4			0.023*** (0.005)
Year-Month FE	YES	YES	YES
Observations	134234		134212
Dep Var Mean	0.274		0.274
Adjusted R^2	0.021		0.020

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine, and on different risk characteristics of customers. Panel A shows results for different subsamples. Panel B shows the results across quartiles of credit score and DTI. The dependent variable is the loan-level profit ratio (profit/initial investment). *Machine* is an indicator equal to one if the loan is underwritten by the machine, and zero if the loan is underwritten by a human underwriter. *Low Credit Score-High DTI* is an indicator equal to one if the debtor's credit score is below the median credit score and the debtor's DTI is above the median DTI in the data, and zero otherwise. "Uncensored" loans are those whose original terms do not extend beyond the end of our sample period. "Completed" loans are those that have been completed during our sample period. "Censored" loans are those whose original terms extend beyond our sample period. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.12 Regression of default prediction errors on loan characteristics.

Model:	(1) ML Model	(2) Linear Model
Loan-to-Value	0.018*** (0.001)	0.021*** (0.001)
Loan Amount	0.015*** (0.001)	0.023*** (0.002)
Term (months)	0.008*** (0.001)	0.012*** (0.001)
Discount	0.013*** (0.001)	0.023*** (0.002)
Credit Score	-0.037*** (0.002)	-0.048*** (0.002)
Homeowner Indicator	0.013** (0.005)	0.035*** (0.006)
Bankruptcy	-0.068*** (0.003)	-0.086*** (0.003)
Debt-to-Income Ratio	0.005*** (0.001)	0.006*** (0.001)
New Car Indicator	-0.011*** (0.004)	-0.013*** (0.004)
Vehicle Age (years)	0.014*** (0.001)	0.022*** (0.002)
Year-Month FE	YES	YES
Dealer FE	YES	YES
Car Make FE	YES	YES
Car Model FE	YES	YES
Observations	112433	112433
Dep Var Mean	0.315	0.373
Adjusted R^2	0.150	0.256

This table reports estimates from panel regressions of the default prediction errors on loan, borrower, and vehicle characteristics. The sample includes historical uncensored loans from January 1997 to December 2012, before the automation experiment starts. The dependent variable is the absolute value of the difference between the actual loan outcome (default or not default) and the predicted default likelihood. The prediction errors used in Column (1) are from the machine learning model developed in Section 3.1. Column (2) uses prediction errors from a linear credit model that estimates a regression of default on the full set of characteristics, including LTV, loan amount, loan term, discount, credit score, homeownership, income, DTI, prior bankruptcy, whether the vehicle is used or new, and vehicle age, as well as year-month, dealer, make, and model fixed effects. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.13 Underwriter selection across demographic characteristics.

Panel A: Without controls			
Dep Var:	(1) Machine	(2) Machine	(3) Machine
Black Worker	-0.009 (0.006)		
Asian Worker		-0.003 (0.007)	
Hispanic Worker			0.014* (0.008)
Year-Month FE	YES	YES	YES
Observations	122246	122246	122246
Dep Var Mean	0.488	0.488	0.488
Adjusted R^2	0.006	0.006	0.007

Panel B: With controls			
Dep Var:	(1) Machine	(2) Machine	(3) Machine
Black Worker	-0.006 (0.007)		
Asian Worker		-0.004 (0.007)	
Hispanic Worker			0.012 (0.008)
Year-Month FE	YES	YES	YES
Dealer FE	YES	YES	YES
Car Make FE	YES	YES	YES
Car Model FE	YES	YES	YES
Observations	117427	117427	117427
Dep Var Mean	0.487	0.487	0.487
Adjusted R^2	0.025	0.025	0.026

This table reports estimates from panel regressions of whether a loan is underwritten by the machine on the racial make up of a zip code in the dealership's location. Panel A shows results without controls. Panel B's regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). The dependent variable (*Machine*) is an indicator equal to one if the loan is underwritten by the machine, and zero if the loan is underwritten by a human underwriter. Black Worker, Asian Worker, and Hispanic Worker represent the percentage of Black, Asian, and Hispanic workers in the total population in the dealership's Zip Code. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.14 Difference in loan profit across demographic characteristics

Panel A: Without controls			
Dep Var:	(1) Loan Profit	(2) Loan Profit	(3) Loan Profit
Machine	0.029*** (0.003)	0.029*** (0.003)	0.029*** (0.003)
Black Worker	-0.004 (0.003)		
Machine × Black Worker	-0.002 (0.002)		
Asian Worker		-0.000 (0.002)	
Machine × Asian Worker		0.003 (0.002)	
Hispanic Worker			-0.005 (0.004)
Machine × Hispanic Worker			-0.001 (0.004)
Year-Month FE	YES	YES	YES
Observations	121844	121844	121844
Dep Var Mean	0.267	0.267	0.267
Adjusted R^2	0.014	0.013	0.014
Panel B: With controls			
Dep Var:	(1) Loan Profit	(2) Loan Profit	(3) Loan Profit
Machine	0.031*** (0.003)	0.032*** (0.003)	0.032*** (0.003)
Black Worker	-0.005* (0.003)		
Machine × Black Worker	-0.002 (0.003)		
Asian Worker		0.001 (0.003)	
Machine × Asian Worker		0.003 (0.002)	
Hispanic Worker			-0.002 (0.004)
Machine × Hispanic Worker			-0.002 (0.003)
Year-Month FE	YES	YES	YES
Dealer FE	YES	YES	YES
Car Make FE	YES	YES	YES
Car Model FE	YES	YES	YES
Observations	117047	117047	117047
Dep Var Mean	0.265	0.265	0.265
Adjusted R^2	0.039	0.038	0.038

This table reports estimates from panel regressions of loan profit on whether the loan is underwritten by the machine, and on the racial make up of a zip code in the dealership's location. Panel A shows results without controls. Panel B's regressions control for loan characteristics (loan-to-value, loan amount, term, discount), borrower characteristics (credit score, homeownership, prior bankruptcy, debt-to-income ratio), and vehicle characteristics (new or used, age). The dependent variable is the loan-level profit ratio (profit/initial investment). *Machine* is an indicator equal to one if the loan is underwritten by the machine and zero if the loan is underwritten by a human. Black Worker, Asian Worker, and Hispanic Worker represent the percentage of Black, Asian, and Hispanic workers in the total population in the dealership's Zip Code. Standard errors are clustered by year-month and dealership, and are shown in parentheses below the coefficient estimates. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.15 Difference in loan profit (%) across dimensions of customers' characteristics.

	High DTI	Medium DTI	Low DTI
Low Credit Score	5.31	3.98	2.39
Medium Credit Score	3.52	2.92	1.77
High Credit Score	2.44	2.45	2.64

This table reports the difference in average loan profit (%) between machine- and human-underwritten loans across two dimensions of customer characteristics: Credit score and debt-to-income (DTI). Loan profit is the ratio of loan-level profit to initial investment. Low, Medium, and High Credit Score (DTI) are tertiles of variable Credit Score (DTI). A borrower with a low Credit Score and high DTI is riskier than a borrower with low DTI and high Credit Score.