Credit Risk - Predictive Modelling

4EK614

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With You Today

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Our services

Credit Risk Team

- Risk Parameters
- Impairment Loss
- AQR
- Regulatory

Our projects

- Model Development
  Model Validation
- Data Analysis
  Data Mining
- Stress Testing
  Impairment
- Methodological Reviews
  Asset Quality Reviews
- LIC©
  Advanced Analytics
- Regulatory Reporting
  Business Intelligence

EY

About This Seminar

Course Structure

Day 1: **Credit Risk, Underwriting Process, Predictive Modelling**
Day 2: Market Risk

Classroom: Microsoft Teams
Time: 9:15 - 12:30

Study materials

1. PowerPoint slides, provided after the course

Prerequisites

1. Basic understanding of statistical and mathematical concepts
2. Elementary knowledge of programming (Python, R, …)

Course Assessment

1. Case study – you can choose market risk and/or credit risk topics:
    a) Credit Risk - Preparation of PD scorecard:
        a) Prepare development sample from portfolio of mortgage loans
        b) Model scorecard using logistic regression (or any technique you want!) and include assessment
    b) Market Risk - TBA

2. Outputs – PPT presentation or PDF, summarizing the abovementioned outputs, and scripts used.

3. Output presentation – short (10-15 minute) presentation about results of this assessment.

Agenda

1. Credit Risk & Banking	W 09:15-09:50
2. Underwriting & Scoring	W 09:50-10:25
3. Predictive Modelling	W 10:30-11:15
4. Scorecard Development	W 11:15-11:50
5. Model Assessment	W 11:50-12:20
6. Q&A	W 12:20-12:30

Operative

Don’t hesitate to ask or comment at any point
Especially since it’s just virtual ☹
We recommend teams for case study
Menti.com – 14 13 31 65

Coursework

Goal

- Your task is to build a PD scorecard using the provided data. The goal is to create a model that will predict a probability of default for each mortgage.
- The presentation contains an overview of a proposed modelling process and some considerations to consider when developing and assessing the model.
- You will be assessed on the "good modelling practice" you employ. Remember, the best model is not necessarily the one with the highest performance metric. Your goal should be to build a scorecard with enough discriminatory power, but the steps taken during the modelling process are most important.

Resources – please write an email to jan.nusko@cz.ey.com

- Mortgage_sample.csv: Modelling dataset with data about 50000 US mortgages
- Mortagage_metadata.xlsx: Data dictionary

- Package suggestions:
  - Python - scorecardpy
  - R - scorecard

Banks

Balance sheet and off-balance sheet of a bank

	Assets	Liabilities
Balance sheet	Cash Deposits at central bank **Loan** Loans to other banks Securities Other assets	**Deposits from customers** Loans from other banks Securities Hybrid instruments Other liabilities **Equity**
Off-balance sheet	Undrawn limits of credit lines Loan commitments Guarantees given Derivatives	Undrawn limits of credit lines Guarantees received Derivatives

What is credit risk?

- The risk that a counterparty fails to meet a contractual obligation

Banking book

- Retail: mortgages, credit cards
- Corporate: Investment property financing, project financing, large corporate lending
- Wholesale: Lending to banks & sovereigns

Trading book

- Counterparty credit risk (CCR): whenever a trade is settled in the future and/or is not "delivery versus payment" (DvP), a firm takes on credit risk

Insurance

- Reinsurer default
- Corporate bond / ABS default / CDS
- Derivative counterparties

Other

- Intermediary: Default on commissions receivable
- Accounts receivable: Non payment of invoice

Components of credit risk

PD

- Probability of Default: The likelihood the borrower will default on its obligation either over the life of the obligation.

LGD

- Loss Given Default: Loss that lender would incur in the event of borrower's default. It is the exposure that cannot be recovered through bankruptcy proceedings, collateral recovery or some other form of settlement. Usually expressed as a percentage of exposure at default.

EAD

- Exposure at Default: The exposure that the borrower would have at default. Takes into account both on-balance sheet (capital) and off-balance sheet (unused lines, derivatives or repo transactions) exposures and payment schedule.

Expected Credit Loss (ECL) = PD x LGD x EAD

Credit risk agenda

Governance

- Risk management function reshaping roadmap
- Credit risk strategy and linkage to business strategy
- Risk appetite framework and statements
- Credit risk processes and segregation of duties
- Model governance framework (model request, design implementation, validation)
- Stress testing framework

Collection services

- Diagnostics on the effectiveness & efficiency of the collections process
- Development of a collections strategy, strategic and tactical (cost-benefit) analysis of available outsourcing options
- Design of a collections framework
- Support with collections technology requirements analysis, selection and implementation of an appropriate solution

Application process

Application scoring

- Business model request specification
- Application scorecard design and validation
- Design and review of the application processes
- Support with application workflow technology

Performing portfolio

Rating models

- Model design / validation / internal audit reviews
- Regulatory compliance
- PD estimation
- Model usage for business purposes

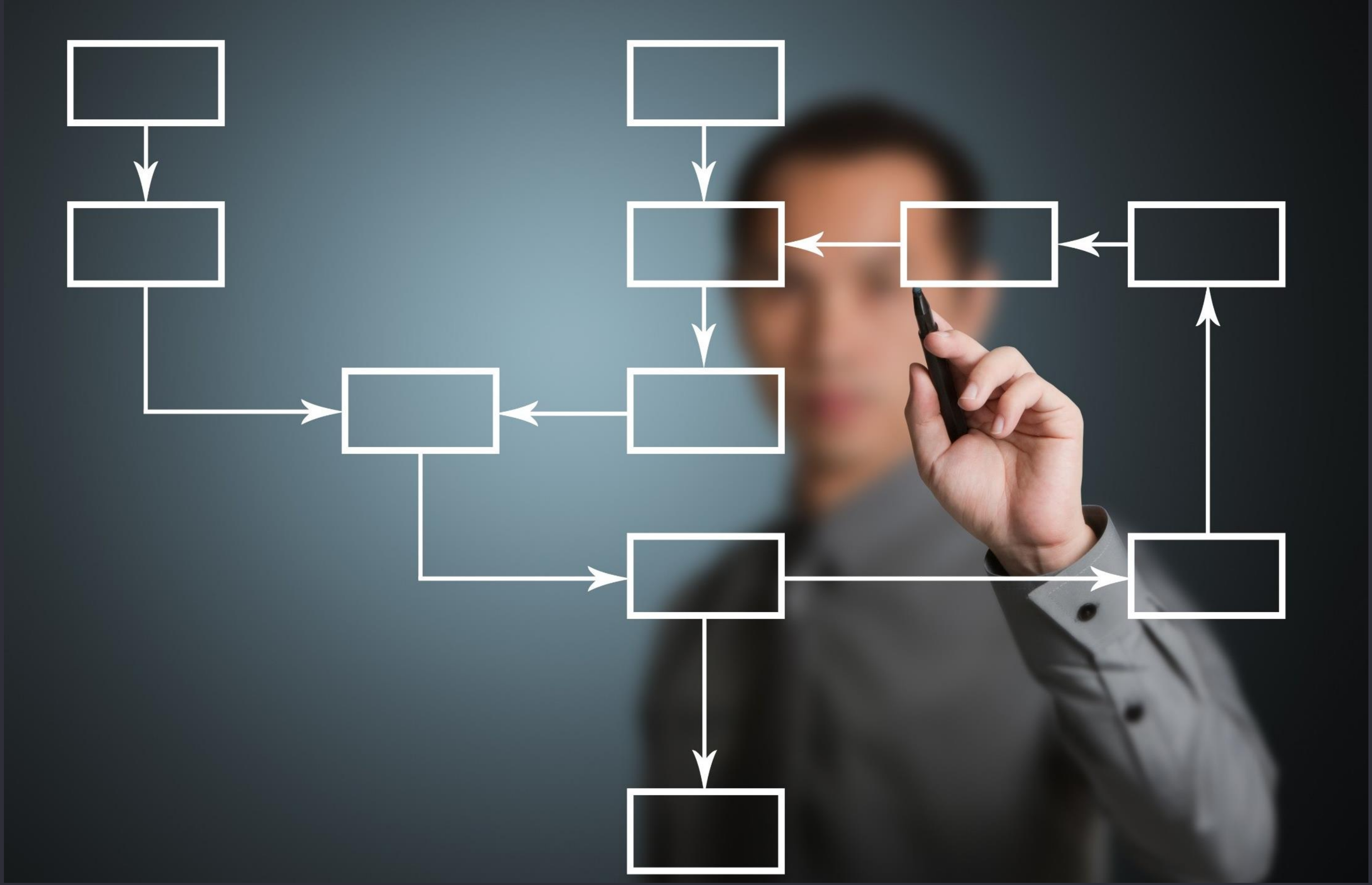
Provisioning

- Design of impairment methodology in line with IFRS
- Effective interest rate and recognitions of fees and commissions
- Back-testing analyses
- Proprietary IT tools

Non-performing portfolio

LGD models

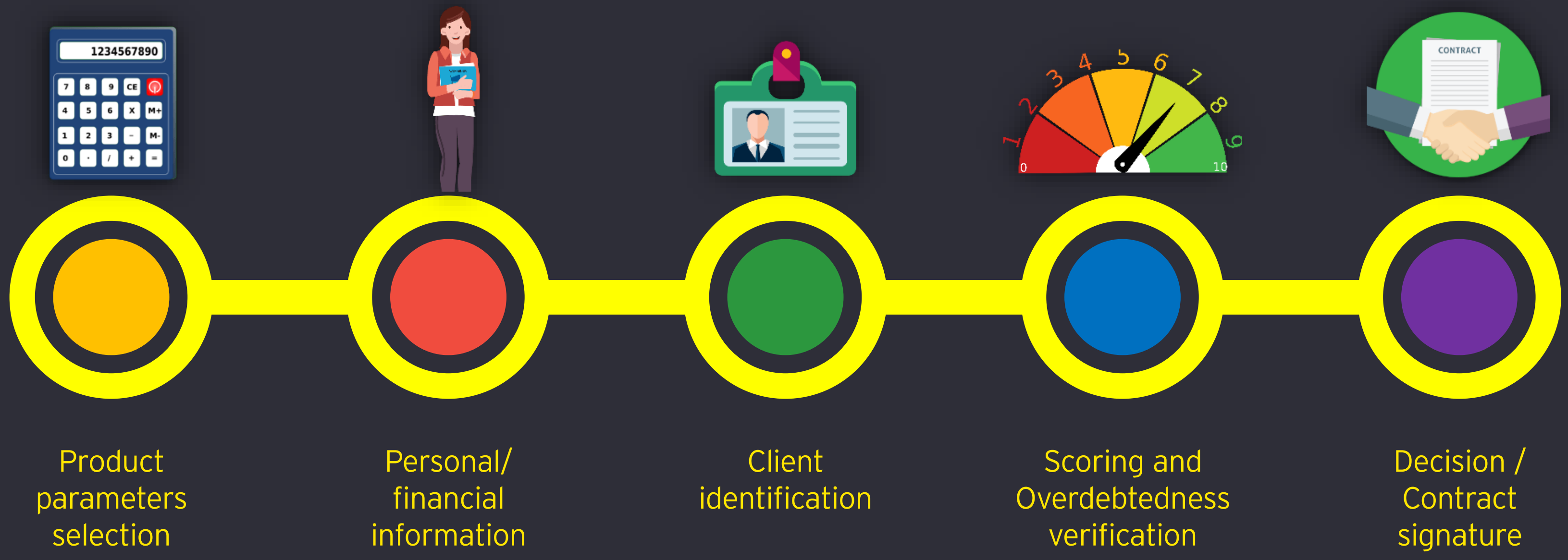
- LGD estimates design and validation
- LGD (scoring) models design and validation
- LGD data warehouse specification
- Collateral valuation scenarios



Underwriting process

Underwriting process

- Underwriting (UW) process is the processing of credit application and making a decision about the final approval or decline of the application.
- Generally the UW process can end up in several different states: approval, decline, cancelation from client side, non-eligibility (for example the applicant is not meeting minimum age criteria, etc.)



Underwriting process

- Client segment is a crucial parameter to the UW process and scoring

Private individuals	Entrepreneurs Freelancers	Small business	Corporates
• Usually automated process • Scoring applications in order to assess riskiness of newly issued loans/credits • Scoring client behavior on monthly basis on credit and deposit products • Large data sets → statistical approach • Need to verify income and over-indebtedness • Credit registers (BRKI, NRKI, Solus)	• Usually automated process with possibly manual inputs • Scoring applications in order to assess riskiness of newly issued loans/credits • Scoring client behavior on monthly basis • Large data sets → statistical approach • No need to verify income and over-indebtedness • Credit registers	• Partially automated process, but mostly manual assessment • Scoring applications for automated products • Process for manual yearly rating (typically financial scoring, qualitative scoring and behavioral scoring) • Sufficient data sets for statistical approach • Credit registers (CRÚ, Cribis, Bisnode, etc.)	• Typically manual assessment on yearly basis (rating process using financial, qualitative and behavioral scoring) • Sometimes not sufficient data to use statistical approach – especially in case of project financing • Industry dependent and seasonal • Credit registers (CRÚ, Cribis, Bisnode, etc.)

Underwriting process

- Underwriting process differs significantly for different products

Mortgage	Consumer loan	Credit card, Overdraft and Revolving	Investment loan
• Financing housing needs • Subject to consumer protection • Requires real estate collateral and insurance • Large financed amount • Typically longer maturity • More thorough and detailed UW process • Partially manual assessment • Loan to value condition • Lower interest rates • Fixation periods • Co-applicants possible	• Purpose or non-purpose • Subject to consumer protection • Can have collaterals or guarantors, but usually it doesn't • Automated, easy and fast UW process • Higher interest rates • Co-applicants possible, but not that frequent as for mortgages • Medium financed amount • Medium maturity • Medium risk	• Credit limit that can be utilized, but it is not a must • Client can flexibly utilize whatever part of the limit he needs to • Grace period • High interest rates • Typically no collaterals • Lower financed amount • Maturity is not specified (contract terminates on request when fully repaid) • High risk • Credit cards come with plastic card	• Typical financing for corporate and small business segments, but also for entrepreneurs • Processed manually • Very high financed amount • Based on business and financial plan • Usually with collaterals and guarantees

Underwriting process

- First step in the process is the assessment of client general eligibility
  - Is the client over 18 years old?
  - Is the client eligible to sign contracts?
  - Is the client on the international sanction list?
  - Is the client a politically exposed person?
  - Has the client a tax domicile in the same country?
  - Does the client agree with all the legally required actions (credit bureau request, information protection principles, general terms and conditions, pre-contractual information, etc.)?

- Second step is the assessment of client eligibility for the given product and channel
  - Is the client below prescribed age when applying for a long term product such as mortgage?
  - Does the client have eligible income for the particular product and process?
  - Does the client have all prescribed documents (valid ID card and valid second ID document)?
  - Is the collateral for the issued loan eligible and sufficient (LTV threshold)?

Underwriting process

- There are several laws and directives that affect the underwriting process

Law on consumer loan

Consumer protection

Mortgage credit directive (MCD)

Consumer credit directive (CCD)

EBA guidelines

Basel Capital Accord

Anti-money laundering (AML)

Consumer needs to be protected from dishonest and malicious practices including intentional over-indebting, but also non-intentional over-indebting – the responsibility of not over-indebting the client is now on the borrower

Market and economy needs to be protected against adverse economic impacts originating in the financial system

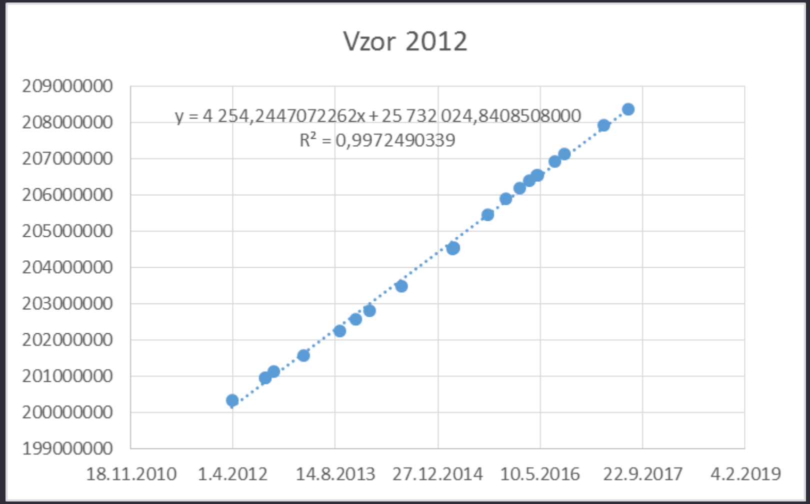
Society needs to be protected against criminal acts and terrorism

Consumer needs to be protected against loosing his money deposited in a bank by irresponsible lending and crediting banks clients

Underwriting process

- Client authentication
- Anti-fraud module

- Expiry date check – ID not expired
- Check on validity in MPSV database
- Issue date consistency check (based on linear regression below)
- Check on issue date – not week-end or public holiday
- Check on address at MěÚ or OÚ
- Control on ID manipulation (color histogram, fonts)
- Check on consistency of bar-code and ID number
- Consistency of sex and birth number (third digit)
- Birth date divisible by 11 after 1953
- Overall control number check
- Expiry date control number check
- Birth date control number check



Underwriting process

- Internal blacklists on phone numbers, ID cards, IČO of employers, ready-made companies

- Frequency checks in on-line underwriting process (applications are tracked with respect to different identificators and their combinations
- Device fingerprint (publicly available libraries)

Hardware: CPU architecture & device memory, GPU canvas, Audio stack
Software: User agent, OS version,
Storage: local storage, session storage
Display: color depth, screen size
Browser customizations: fonts, plug-ins, codecs, mime types, time zone, user language,
Miscellaneous: floating point calculations, callbacks / objects to DOM

  - Phone number
  - Account number
  - ID card number
  - E-mail address
  - Birth number
  - IP address

- Geolocation (via IP address and Google API) – can be used for anti-fraud as well as for scoring

- Checks on discrepancy between past applications with the same identifiers

Underwriting process

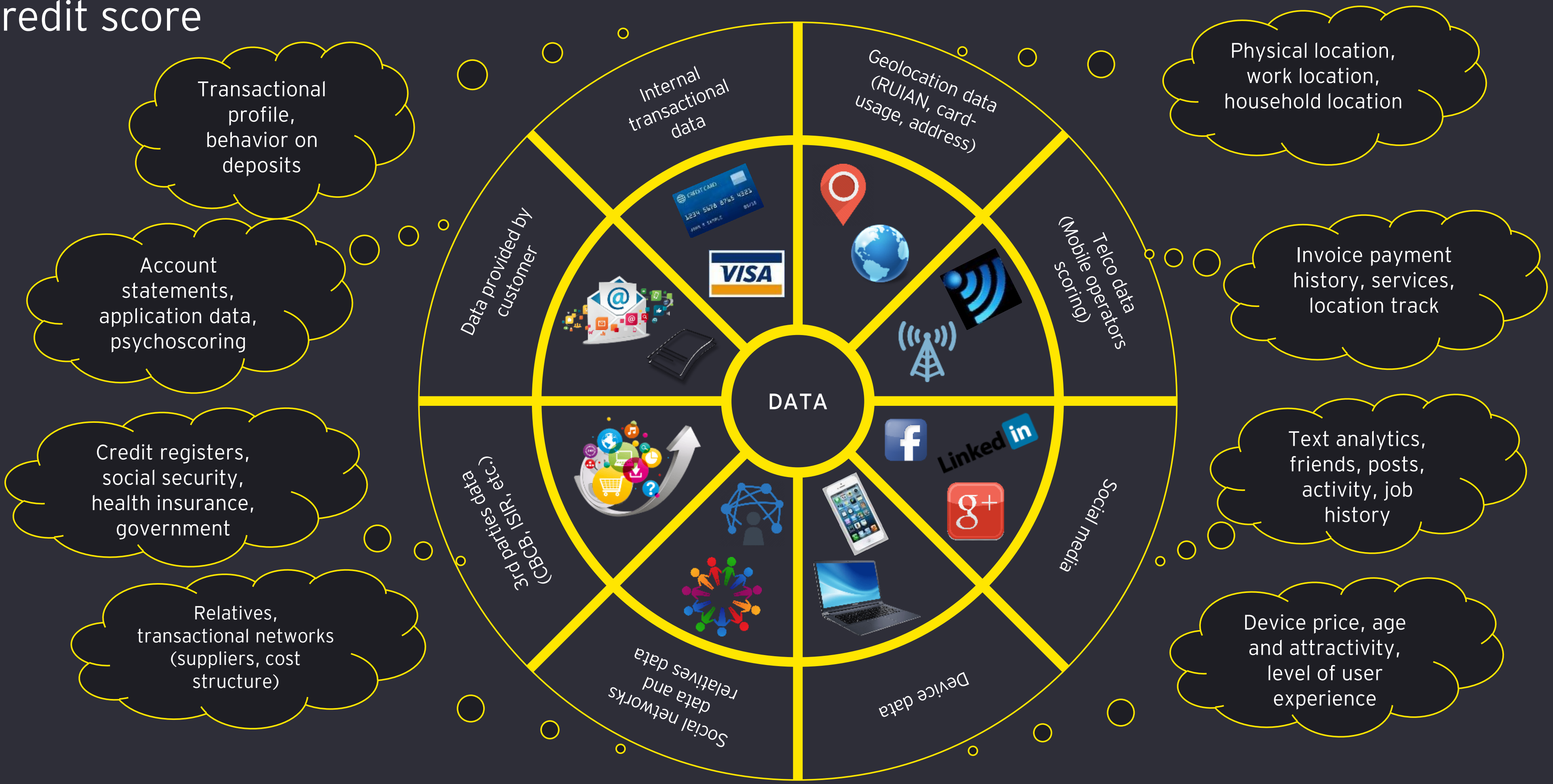
- Individuals / Entrepreneurs:
  - BRKI – Banking Register of Client Information
    - Information about applications and loan contracts shared among the banks operating in Czech Republic. Generally only banks can access it.
    - Information is stored in BRKI during the existence of credit relationship and 4 years after it terminates. If the contract with the bank has not been signed is this information in BRKI stored for one year.
  - NRKI – Non-Banking Register of Client Information
    - Information about applications and loan contracts shared among non-bank credit providers. Generally only those that participate on the sharing can access it.
  - SOLUS
    - Information about applications and loan contracts shared among participating credit providers and some other companies. Generally only those that participate on the sharing can access it. It contains both – register of negative as well as register of positive information.
    - In SOLUS participate also TELCO companies and utility providers.

CRÚ

- Companies / Entrepreneurs:
  - CRÚ – Kreditní Registr Úvěrů
    - Information about loan contracts of entrepreneurs and companies – compulsory register operated by Czech National Bank.

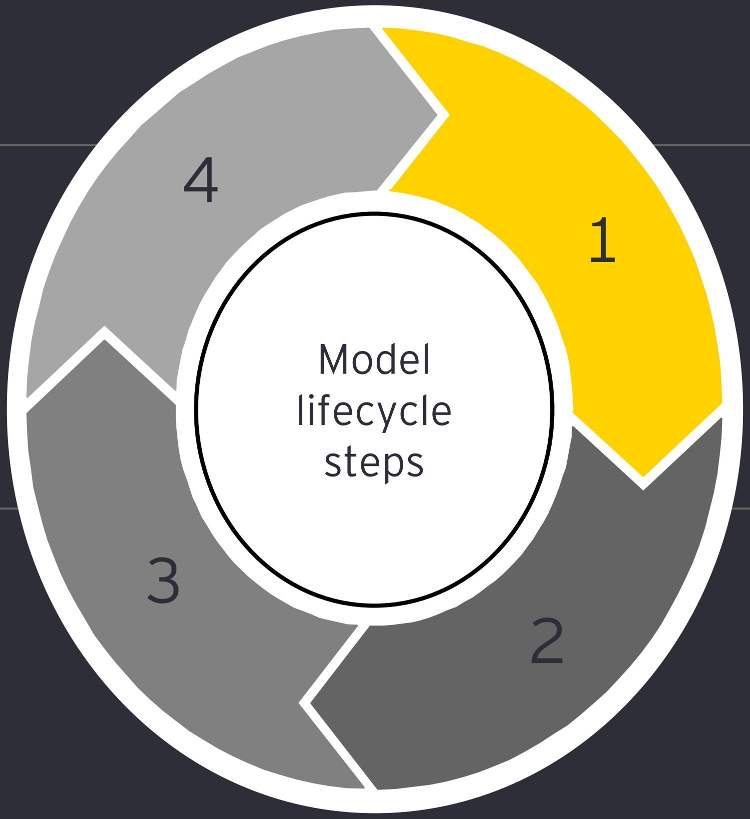
Underwriting process

- Scoring is one of the tools to measure the creditworthiness of a business or person. It is the result of scoring, where different scales are given different weight. This procedure results in a credit score



Predictive modelling

Predictive Modelling - Model life-cycle



Model request
Business line
Management

Model development
Management
Risk

Model implementation & usage
IT & data
Loan approval
Capital requirement calculation

Model monitoring & review
Monitoring
Independent review
Internal audit

Predictive Modelling - Goal

- Problem to be solved:

single

own house

university degree

29 years

i=1 i=2 i=3 i=4 …..

predictors

targe
t

find a function f such that

$$\boxed{T(f(age_i, status_i, education_i, housing_i, \ldots) - \mathrm{I}[i \text{ defaulting in 1 year from snapshot }])}$$

is in some sense minimized

Can be numeric, ordinal, nominal or even missing

Attains only values 0, or 1

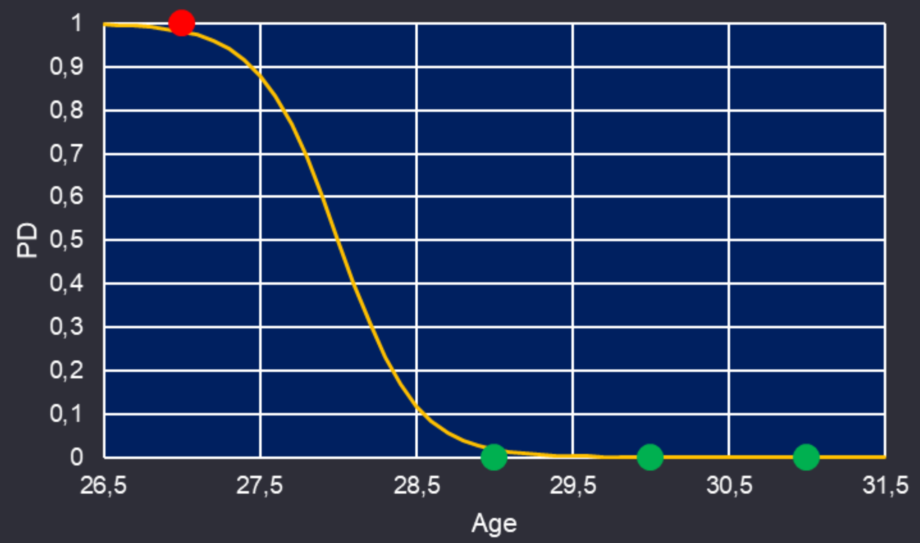
the value f(.) we call probability of default (PD)

Predictive Modelling - Discrimination

Predictive Modelling - Workflow

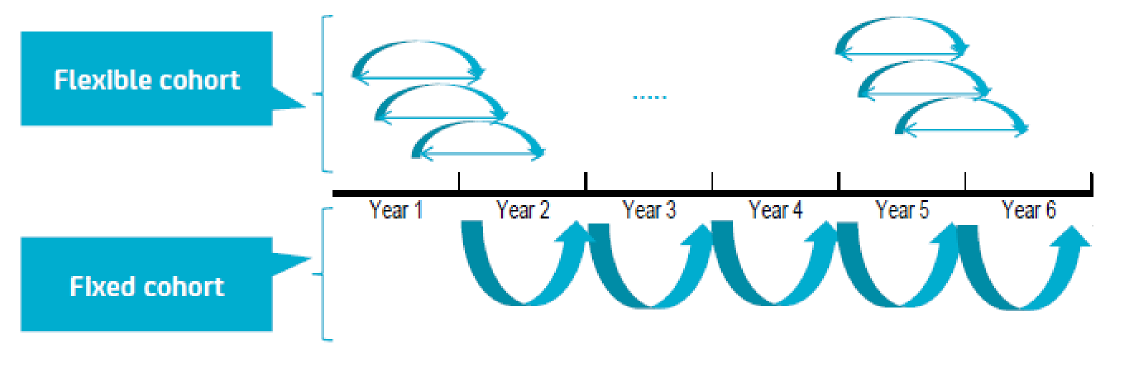
- 1) Data exclusions
- 2) Missing values analysis
- 3) Outlier treatment
- 4) Variable transformation (feature engineering)
- 5) Univariate analysis
- 6) Correlation analysis
- 7) Modelling
  - Selection of shortlist of variables
  - Estimation of coefficients based

Name	Age	Status	Education	Housing	Target
Adam	29	single	high school	rent	0
Annie	27	single	elementary	with parents	1
Jane	31	single	high school	own house	0
John	30	married	university	mortgage	0



Predictive Modelling - Sample definition

- Since we will be using a regressive approach, we need to keep in mind that we cannot have dependent observations.
- To avoid this, a cohort approach is used:
  - Flexible cohort – fixed number of snapshots after first observation
  - Fixed cohort – fixed snapshot date (e.g. from every September)
- For our target, we define a "performance" window – usually 12 months
- No balancing needed ;)
  - Unless we're talking about LDP portfolios



Predictive Modelling - Linear regression

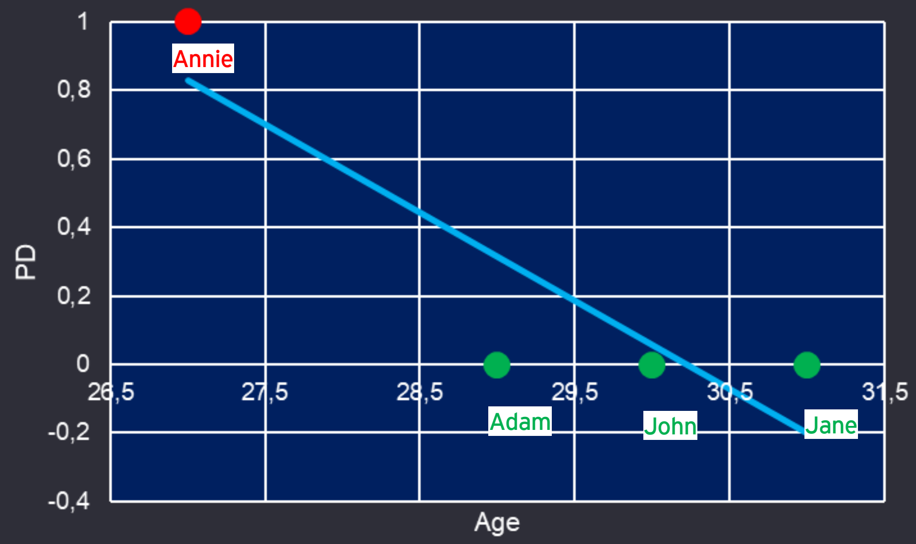
- Problem to be solved:

Historical data with already known target value

Name	Age	Status	Education	Housing	Target
Adam	29	single	high school	rent	0
Annie	27	single	elementary	with parents	1
Jane	31	single	high school	own house	0
John	30	married	university	mortgage	0

We choose linear function

$$f(\vec{x}) := \alpha + \sum_{j=1}^{k} \beta_j x_j$$



Predictive Modelling – Logistic regression

- Problem to be solved:

single

own house

university degree

29 years

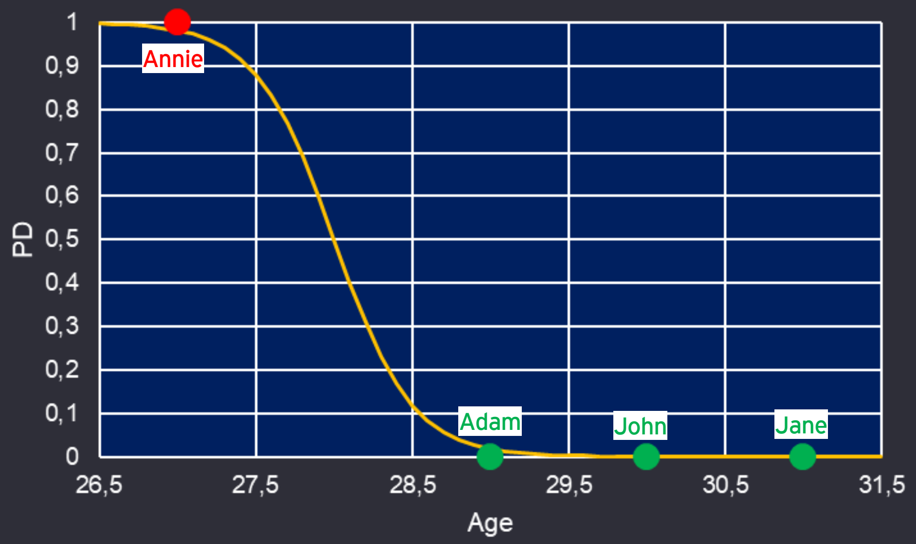
i=1 i=2 i=3 i=4 .....

Historical data with already known target value

Name	Age	Status	Education	Housing	Target
Adam	29	single	high school	rent	0
Annie	27	single	elementary	with parents	1
Jane	31	single	high school	own house	0
John	30	married	university	mortgage	0

We choose logistic function

$$f(\vec{x}) := \frac{1}{1 + e^{-\alpha - \sum_{j=1}^{k} \beta_j x_j}}$$



Predictive Modelling - Logit

- We can choose other functions, but market standard is to use the logit link function

- Using linear function is not proper as it can give estimates above 1 or below 0, which is not convenient for estimating probability of default

- Selection of the link function if it preserves the output between 0 and 1

- The reason for choosing logit function instead of others is mainly interpretational – the log-odds ratio defined below is a linear combination of the predictors

$$Log - odds\ ratio = \ln\left(\frac{PD}{1 - PD}\right) = f^{-1}(PD)$$

- By central limit theorem under very general conditions the log-odds ratio distribution converges in distribution to a normal distribution

Predictive Modelling - Prediction

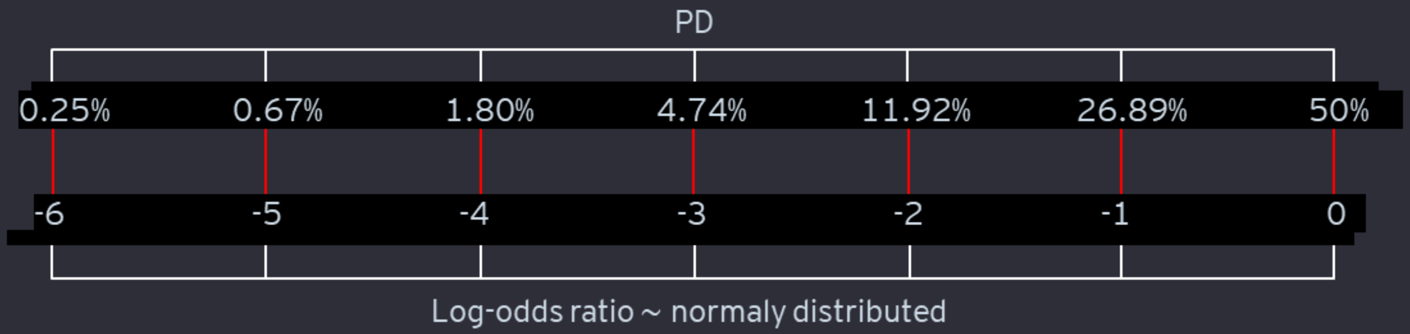
- Let's say we have processed our data (deduplication, formatting, primary keys, consistency checks…)
- We could take advantage of models with some sort of elimination
- E.g. – Lasso regression
  - Least absolute shrinkage and selection operator
  - Performs both variable selection and regularization

> Out of 649 parameters, 192 were set exactly to zero and the obtained lasso model has 457 parameters. Among these parameters, 139 have estimated values in absolute value greater or equal to 0.1. We will present 20 coefficients with highest absolute values.

- Is this a good model?

Predictive Modelling - Scorecard

- Scorecard points (score)



- The motivation is to derive a scale such that:
  - It's a linear combination of log-odds ratio
  - More score points means lower PD
  - Double odds ratio corresponds to a prescribed number of score points A :

$$Score\ points_i = \alpha + \beta * \ln\left(\frac{PD_i}{1 - PD_i}\right)$$

$$A = \alpha + \beta * \ln\left(\frac{2 * PD_i}{1 - PD_i}\right) - \alpha - \beta * \ln\left(\frac{PD_i}{1 - PD_i}\right) = \beta * \ln 2 \ \Rightarrow \ \beta = \frac{A}{\ln 2}$$

- B score points corresponds to a prescribed PD value x :

$$B = \alpha + \frac{A}{\ln 2} * \ln\left(\frac{x}{1 - x}\right) \ \Rightarrow \alpha = B - \frac{A}{\ln 2} * \ln\left(\frac{x}{1 - x}\right)$$

A is usually set to be 50 score points

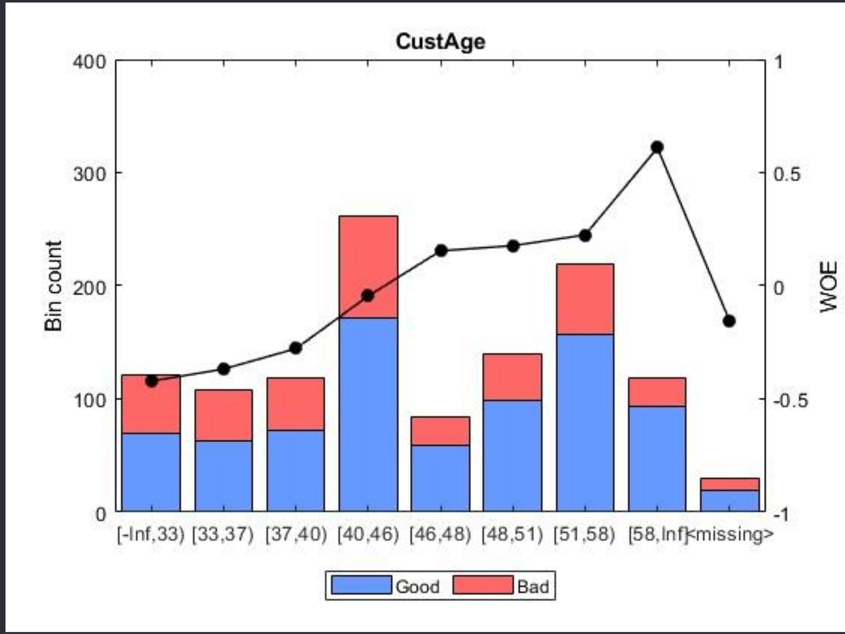
B is usually set to 500 score points and the corresponding $x = \frac{1}{51}$

Scorecard points ~ normaly distributed

Predictive Modelling - Binning

- Another standardly used technique is binning of predictors and WoE transformation:
  - Weight of evidence for i-th bin: $WoE_i := \ln\left(\frac{GOODS_i/BADS_i}{GOODS/BADS}\right)$

	BIN	GOODS	BADS	DR	WoE
1	[-inf,33)	69	52	0,429752	-0,42156
2	[33,37)	63	45	0,416667	-0,36795
3	[37,40)	72	47	0,394958	-0,27790
4	[40,46)	172	89	0,340996	-0,04556
5	[46,48)	59	25	0,297619	0,15424
6	[48,51)	99	41	0,292857	0,17712
7	[51,58)	157	62	0,283105	0,22469
8	[58,inf)	93	25	0,211864	0,60930
9	MISSING	19	11	0,366667	-0,15787



- Why binning? solves leverage points, solves informative missings, solves non-numerical (either ordinal or multinomial) variables, assesses robustness
- Why WoE transformation? normalizes predictors values, enables easy interpretation (under reasonable conditions always attains negative and positive values, zero value represents portfolio default rate)

Predictive Modelling - WoE

Predictor	Group	Scorecard Points	WoE	DR	Percentage of population	Coefficient
Intercept		25				-3,6578
Age	<25	0	-1,0109	18,1%	16,2%	-0,6572
	<35	27	-0,4535	11,2%	23,3%	
	<55	83	0,7352	3,7%	33,9%	
	>=55	111	1,3272	2,1%	25,1%	
	Missing	50	0,0420	7,1%	1,5%	
Education	Elementary	0	-1,0188	18,2%	6,9%	-0,8213
	Vocational	18	-0,7154	14,1%	15,6%	
	High school	82	0,3762	5,2%	38,1%	
	University	83	0,3877	5,2%	38,5%	
	Missing	85	0,4215	0,0%	0,9%	
Housing type	With parents	0	-0,8902	16,3%	10,9%	-0,7765
	Rent	2	-0,8489	15,8%	13,9%	
	Cooperative	44	-0,1144	8,3%	21,5%	
	Mortgage	105	0,9786	2,9%	42,9%	
	Own	82	0,5794	4,3%	9,7%	
	Missing	79	0,5216	0,0%	1,0%	
Marital status	Single	0	-0,8118	15,3%	29,4%	-0,5903
	Married	85	1,1710	2,4%	21,5%	
	Divorced	47	0,2865	5,7%	36,8%	
	Widowed	76	0,9634	3,0%	10,6%	
	Missing	76	0,9736	0,0%	1,7%	

$$Total\ scorecard\ points = Intercept\ scorecard\ points + \sum_{k=1}^{m} Variable_i\ scorecard\ points$$

- WoE is the new value of binned predictor
- Coefficient is the estimated parameter from logistic regression corresponding to the variable or to the absolute term (intercept)
- In case number in some bin is zero, we need to compensate: $WoE = \ln\left(\frac{(BADS_i + 0.5)/(GOODS_i + 0.5)}{BADS/GOODS}\right)$
- Missing category can be treated
- Scorecard points serve as a standardized linear transformation of log-odds so that certain criteria are met – it is motivated mainly by interpretation
- Coefficients should be negative when using WoE

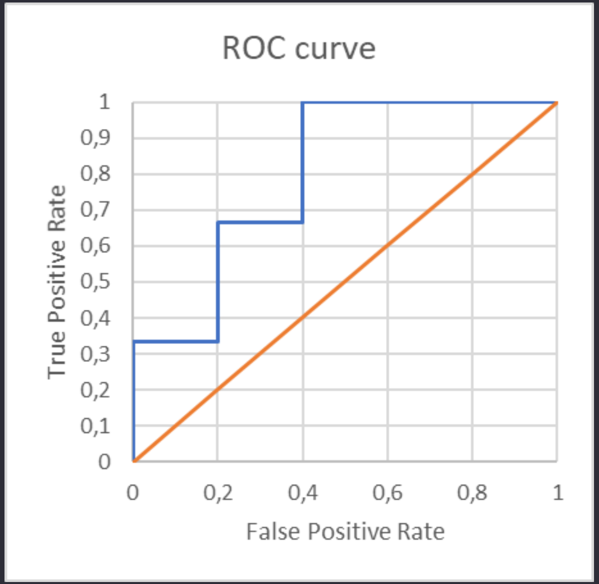
Model performance - GINI

- ROC (Receiver Operation Characteristics) curve, GINI
- Measuring discriminatory power – only ordering matters, not the actual score values

True positive rate if we sort the clients increasingly by the score value, the true positive rate can be calculated for i-th observation as the number of observations with target=1 and index lower or equal to i divided by the total number of observations with target=1

False positive rate if we sort the clients increasingly by the score value, the false positive rate can be calculated for i-th observation as the number of observations with target=0 and index lower or equal to i divided by the total number of observations with target=0

Client	Event	Score
Annie	1	325
Paul	0	398
Lisa	1	415
Jane	0	463
Jack	1	499
Adam	0	520
John	0	611
Mary	0	672



AUC (Area Under Curve) = 1/3*1/5+2/3*1/5+3/3*3/5= 4/5=0.8

GINI = 2*(AUC-0.5)=0.6

- GINI attains values between -1 and 1, but relevant are only values between 0 and 1
- GINI=0 stands for theoretical random model (no predictive power)
- GINI=1 stands for perfectly discriminating model

Model performance – Somers' D

- **Somers' D** is a measure of association between two variables X and Y calculated as follows:

$$Somers'D(X,Y) = \frac{N_C(X,Y) - N_D(X,Y)}{N_C(X,X) - N_D(X,X)}$$

- $N_C(X,Y)$ is the number of **concordant pairs** (x_i, y_i) and (x_j, y_j), i.e. either $x_i < x_j$ and $y_i < y_j$, or $x_i > x_j$ and $y_i > y_j$ and
- $N_D(X,Y)$ is the number of **dis-concordant pairs** (x_i, y_i) and (x_j, y_j), i.e. either $x_i < x_j$ and $y_i > y_j$, or $x_i > x_j$ and $y_i < y_j$.

- Somers' D is more general measure than GINI as it can be used on other than binary targets
- For binary target and no ties in the independent variable it equals GINI
- Clearly: $N_D(X,X)$=0

Model performance - Somers' D

- Illustrative example (X = grade, Y = time spent studying):

	Time spend studying	
Grades	Minimal	Extensive
Bad	20 (a)	5 (b)
Good	6 (c)	10 (d)

$N_C(X,Y) = \mathrm{a} \cdot d$
$N_D(X,Y) = b \cdot c$
$N_C(X,X) = (a+b) \cdot (c+d)$
$N_D(X,X) = 0$

- Using the formula:

$$Somers'D(X,Y) = \frac{N_C(X,Y) - N_D(X,Y)}{N_C(X,X) - N_D(X,X)}$$

$$Somers'D(X,Y) = \frac{200-30}{400-0} = 0.4250$$

vs.

$$Somers'D(Y,X) = \frac{200-30}{390-0} = 0.4359$$

Somers' D differentiates between independent and dependent variable

Representativeness/Stability - PSI

- PSI (Population Stability Index) is a measure of difference between two discrete distributions
- It is typically used in order to assess representativity – i.e. assess whether distribution of a binned variable differs in two different data samples which are typically from two different time periods (threshold of 0.2 is frequently used)

$$PSI = \sum_{i=1}^{n} (Actual\%_i - Expected\%_i) * \ln\left(\frac{Actual\%_i}{Expected\%_i}\right)$$

where n is number of bins

Score bands	Actual %	Expected %	Ac-Ex	ln(Ac/Ex)	Index
< 251	5%	8%	-3%	-0,470	**0,014**
251–290	6%	9%	-3%	-0,410	**0,012**
291–320	6%	10%	-4%	-0,510	**0,020**
321–350	8%	13%	-5%	-0,490	**0,024**
351–380	10%	12%	-2%	-0,180	**0,004**
381–410	12%	11%	1%	0,090	**0,001**
411–440	14%	10%	4%	0,340	**0,013**
441–470	14%	9%	5%	0,440	**0,022**
471–520	13%	9%	4%	0,370	**0,015**
520 <	9%	8%	1%	0,120	**0,001**
Population Stability Index (PSI) =					**0,1269**