Final report

AI-based financial risk assessment for Circular Business Models (AID-CBM)

List of Content

Summary

The AID-CBM project ran between November 2019 and March 2022 and has investigated the research questions: “How can the banks/financiers estimate market value and risk in Circular Business Models with the help of AI?” and “What are stakeholders’ reconfigured roles in circular business ecosystems?”

The project conducted 25 interviews, two workshops and a survey with 24 respondents to explore the research questions, both in depth and in broad collaboration between stakeholders. The results of the project include a structured overview of the challenges of financing Product-as-a-service-based Circular Business Models, an overview of a Circular business ecosystem including financiers, and 13 different suggested solutions to the challenges of financing Circular Business Models. The solutions are presented according to the three categories of bank risk assessments (Collateral or asset-based, Business case-based and Relationship-based) and they have been packaged in popular science-format for dissemination and communication to a broad set of stakeholders.

The project also developed a machine learning model that is able to predict the residual value of used garments with a probability of (at best) 57,77%. The model was trained using open source-data, and the results indicate that residual value predictions from objective AI-based tools could be a relevant support for collateral-based credit assessment. The AI-model has been published as open source.

The project results were presented in a webinar with more than 100 participants on March 8th 2022 and have been consolidated in two journal articles (under review), two conference articles, a separate report on the AI work, this final report and the 13 solutions in power point format. The latter will be used for broader dissemination through social media, to industry and stakeholders.

Sammanfattning

AID-CBM-projektet har pågått mellan november 2019 och mars 2022 och har undersökt forskningsfrågorna: "Hur kan banker/finansiärer uppskatta marknadsvärde och risk i cirkulära affärsmodeller med hjälp av AI?" och "Vilka är intressenternas nya roller i cirkulära affärsekosystem?"

I projektet gjordes 25 intervjuer, två workshops och en enkätundersökning med 24 respondenter för att utforska forskningsfrågorna, både på djupet och i bred samverkan mellan intressenter. Resultaten av projektet inkluderar en strukturerad översikt över utmaningarna med att finansiera produkt-som-tjänst-baserade cirkulära affärsmodeller, en översikt över ett cirkulärt affärsekosystem inklusive finansiärer, och 13 olika föreslagna lösningar på utmaningarna med att finansiera cirkulära affärsmodeller. Lösningarna presenteras enligt de tre kategorierna för bedömning av risk som används av banker (Säkerhets- eller tillgångsbaserade, Business case-baserade och Relationsbaserade) och de har paketerats i populärvetenskapligt format för spridning och kommunikation till en bred målgrupp.

Projektet utvecklade också en maskininlärningsmodell som kan förutsäga restvärdet på begagnade plagg med en sannolikhet på (i bästa fall) 57,77%. Modellen tränades med hjälp av öppen data, och resultaten tyder på att förutsägelser om restvärde från objektiva AI-baserade verktyg kan vara ett relevant stöd för säkerhetsbaserad kreditvärdering. AI-modellen har publicerats som öppen källkod.

Projektresultaten presenterades i ett webbseminarium med fler än 100 deltagare den 8 mars 2022 och har konsoliderats i två tidskriftsartiklar (under granskning), två konferensartiklar, en separat rapport om AI-arbetet, denna slutrapport och de 13 lösningarna i power point-format. De senare kommer att användas för bredare spridning genom sociala medier, till industrin och andra intressenter.

Background

In the last couple of years, a number of reports and studies have stated a clear and strong relationship between CE and CO2 emissions (e.g. CEE 2016, Club of Rome 2016, Material Economics 2018, EEA 2018, Linder et al 2018). CE, with its focus on retaining value in products and materials as high as possible for as long as possible, has an inherent carbon emission reduction impact, since flows of materials, goods and energy are reduced and slowed down. In EMF terms (2013) the tighter the loops the more energy saving and CO2 reduction potential there is. Tighter loops are assumed to be incentivized and enabled by CBMs, such as Product-as-a-service (PaaS) and functional sales models, where the ownership of the product is retained by the manufacturing/selling firm, instead of being transferred to the customer (whether a business or a consumer). Shifting to these models is however closely linked to perceived increased risk for both the shifting company and the financier (Linder and Williander 2015, Rizos et al 2016, Pavoni 2019).

In this project, we have built upon the results of two earlier projects: Financing circular business models – Risks and opportunities (Vinnova no 2017-03313), and Tools for optimizing revenue and profitability in circular business models (Vinnova no 2018- 04694). Both projects have shown that there are still tremendous challenges in transitioning from selling goods to selling services or functions, and one important challenge is the availability of capital for expansion. Risk willing capital in general is not scarce, but these models involve new perceived risks, such as difficulty in establishing if the business case is strong enough or not – due to lack of benchmark– and difficulty in finding safe collateral - when new types of products in CBMs lack established secondhand markets and clear residual values. The projects have also clearly shown that established risk assessment models with financiers (e.g. banks) need to be developed to incorporate these new types of business models, and that the role of the financier changes. This is a challenge but also an opportunity for the financial sector/banks, as they need to develop their understanding of the new models and thus has the opportunity to become more of a strategic partner for the customer and its business ecosystem. In a landscape where the shift to CBMs is scaled up to incorporate several sectors of industry and society, the role of the bank will evolve. The bank has a unique position to act as a “spider in the web” as an enabler and “securer” of transactions - data and money.

These findings from our own projects, align very well with a report from the European Commission (2019), exploring how to improve access to finance for CE projects. This report states that one of the two main financial risks for CE projects is the value of the underlying collateral, and then concludes that one of the key problems is the “lack of or insufficiently developed risk assessment models for circular projects and businesses “(EC 2019, p 12), which is exactly what we have targeted with this project.

Recent advances in artificial intelligence have demonstrated tremendous success in tasks such as image classification (Tan & Le, 2019) and image caption generation (Xu, et.al., 2015). The technique behind much of this progress is called deep learning, because of its internal deep structure, that enables learning hierarchical internal representations of data automatically. Deep learning has the capacity of modelling nonlinear functions, and to work on data of many different modalities (categorical, numerical, images, text, video, audio, etc), sometimes in combination at the same time.

It has become the state-of-the-art technique for many artificial intelligence applications such as face-recognition, autonomous driving, and even to play video-games (Mnih, et.al., 2013) and board-games (Silver et.al., 2016). Deep learning has also been applied to financial forecasting (Heaton, et.al., 2017) and mortgage risk prediction (Sirignano, et.al., 2016). Peerun et.al., 2018, trained a deep learning model to predict the value of second-hand cars, based on features from online car sales.

The papers above demonstrate the feasibility of predicting financial data using machine learning techniques, but they are not leveraging the information from complete online advertisements. In this project, we have investigated the predictive quality of openly available second-hand market data on the web, including product images. We have investigated how to best develop and train machine learning models that will leverage the predictive power in this data using state-of-the-art deep learning predictors to reach the goals of the project.

Based on this, the project was started with the goal to, with the help of AI, reduce uncertainties of future value of products, thereby increasing the willingness of financiers to take part in the development towards new circular business models. The goal was to answer the following research questions:

1. How can the banks/financiers estimate market value and risk in CBMs with the help of AI?
2. What are stakeholders' reconfigured roles in circular business ecosystems?
    - Banks' role in the business ecosystem as a guarantor of agreements, data, payments, collateral etc.
    - Roles of new actors, such as technology-based companies (as innovation enablers by supporting predictive risk assessment tools) or platform owners (by creating online marketplaces, for reuse as well as repair and refurbishment of products)

Project Work

The project ran from 2019-10-15 until 2022-03-31. RISE was the research partner and project manager and the project ran together with two partners: Skandinaviska Enskilda Banken AB and Nordea Bank ABP. The work has been structured in five work packages, all lead by RISE.

WP 1 – Project Management

Activities related to the project as an organisation, including meetings, workshops, information sharing within the project team and with the reference group, and internal and external reporting.

Two joint meetings with all project stakeholders have been held:

- One initial kick-off workshop
- One final webinar also including an external audience

In addition to this, one workshop has been organised for the project partners and part of the reference group to explore new business models/value propositions of the financier.

All reporting to Vinnova have been delivered on time.

WP 2 – Existing solutions: Residual value and risk assessments and WP 4 – Explore the new Business Ecosystem

The activities of work packages 2 and 4 have, to a great extent, been performed jointly as the challenges and solutions for estimating residual value and risk assessment in circular business models have been understood from the perspective of actors and existing relations along the business ecosystems (e.g. product companies, banks, other financial actors, insurance companies, etc.). From the initial kick-off workshop, it was clear that exploring both the current processes and models of the banks and financiers, and the possible future business ecosystems, could best be handled in a joint process with the purpose of finding solutions – whether belonging to the business ecosystem or not.

The following activities were carried out:

A literature study was performed to explore and gain understanding of the research status for AI in combination with Circular economy, business ecosystems, and financing. We built a framework consisting of different combinations of keywords to identify relevant literature that look at the cross-section of these four topics. Figure 1 illustrates the framework applied in literature search.

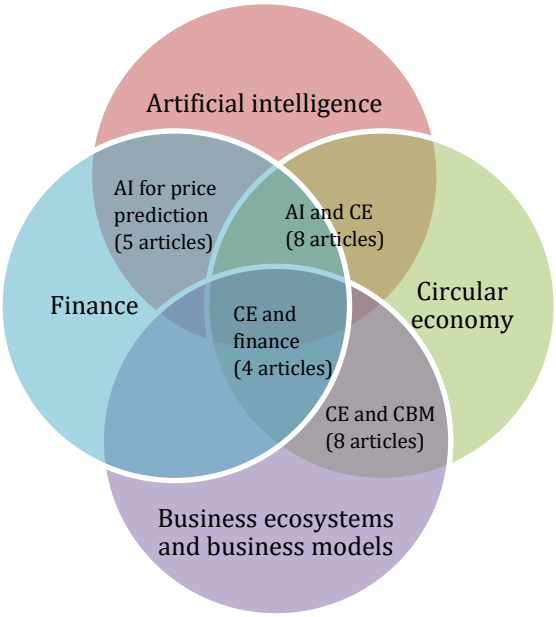

Figure 1. Visualization of the literature search framework

Data collection

In total 25 interviews were conducted with actors along the business ecosystem, including eight financial actors, two OEMs from clothing and white goods industries, and six 'circularity-enablers' offering digital and platform-based services such as insurance, sharing or second-hand marketplaces, and subscription financing solution. The focus of the interviews was on understanding circularity visions and strategies, valuation of products in CBMs, financial risk assessment, and relevant data needed in future business ecosystems.

Two workshops were held. The first one (in Jan 2020) was run with two OEMs, four financial actors (two banks, a public credit institute and an insurance company), and three technology enablers. The "Six thinking hats" method (de Bono, 1985) was applied, and the focus of the workshop was on developing a vision for future circular and digital business ecosystems, by answering questions like "What type of information is critical for banks to be willing to take risks in new CBMs with new collateral?" and "What are the most important aspects that digital technologies such as machine learning can add to risk assessment of collateral in CBMs, when historical data is missing?"

The second one (in the beginning of 2021) was run as a group discussion with three OEMs and three financial actors (two banks and one public credit institute). The workshop used the business model canvas (Osterwalder & Pigneur, 2010) as a framework to map new value creation and value capture logic for a hypothetical financial actor that would offer financing services to manufacturing companies that sell PaaS in B2B or B2C contexts. The documentation was done in Mural.

To further strengthen the dialogue between financiers and potential and existing product-as-a-service companies the project also organized "case meetings" between the two banks and three examples of PaaS companies (one start-up, one SME and one larger company) each. These six dialogues were overheard by one of the researchers and resulted in several ideas for financing solutions.

The results from the interviews and the workshop were expanded to involve a broader range of PaaS companies through a survey about financing PaaS models. The survey was launched in spring 2021 and investigated the product characteristics and company's type of PaaS offer (as subscription, function sales, short term/long term rentals, and/or performance-based), ownership setup, and turnover, as well as need for financing and financing solutions available, and the results were triangulated with the interview and workshop results. The survey was sent to 39 companies that have a PaaS business model in at least one product or category of products. Out of the 39 companies, 24 responded to the survey.

Analysis

A compilation of interview notes and summaries using open coding was made after the interviews, and these preliminary results were complemented with the workshop results (in the form of notes and Mural documentation) and the survey responses. Besides structured analysis of the responses to the close-ended questions, responses from the open-ended questions generated further input for categorizing alternative financial solutions relative to the type of PaaS company and its sector.

The analysis resulted in a structured description of the challenges of financing of CBMs, relating them to two of the three risk assessment categories of the bank (collateral and business case). A first gross list of 16 potential solutions to financing of circular business models was also created. The solution list was run through a training session with one of the partner companies (Nordea) and further scrutinized in the work with the submitted journal paper "Financing Solutions for Circular Business Models" (see WP5 below). Finally, the solution list was narrowed down to 13 different solutions.

WP 3 – AI model and programme

Within work package 3 we implemented, trained, and evaluated deep learning techniques to predict market value of used items based on data collected from the on-line platform Tradera. The work package began with data collection and data curation to ensure that the data was of acceptable quality. The data contained images and short and long item text descriptions from auction ads.

The activities resulted in several AI Models for extracting and calculating residual value based on second-hand market data and a demo AI program based on the model. A comparison analysis was carried out where we analysed how much predictive power lies in text and image input representations, respectively. Our results showed that there is much signal in both text and images to estimate second-hand value of clothing items, and by combining both text and images the best results were achieved. The trained models are free to use and are published as open source at https://github.com/edvinli/AI-CBM.

As a further evaluation step, we also compared the AI models to humans. A form was sent out to and answered by 32 humans, where they tried to solve the same problem as the machine learning models (estimating the second-hand price of auction items). This lets us quantify how hard the problem is, and better evaluate the machine learning models.

WP5 – Dissemination and Communication

The goal regarding dissemination and communication of project results included writing and presentation of at least one academic article, a workshop on CE and CBMs for the Academy of Management annual meeting in 2021 and a final report and other results dissemination material

targeted to relevant practitioners in Sweden. We decided not to publish and perform a workshop at the Academy of Management. This was partly due to covid-19, which stopped the physical conference, and partly due to timing of our results analysis.

We did deliver on the rest of the dissemination goals, and also communicated at several additional occasions and venues.

The project has written, published and/or presented results in the following academic venues:

- Written and presented the short paper "Financing solutions in Future Circular Business Ecosystems" at the ISPIM conference, held in Berlin on the 21st - 23rd June 2021.
- Submitted the conference paper "Residual value prediction using deep learning for circular economy" to SIGKDD Conference on Knowledge Discovery and Data Mining in March 2022, pending reviews (due May 2022).
- Submitted the journal paper "Financing of Circular Business Models: The case of Product-as-a-service" to Circular Economy and Sustainability. The paper was submitted on March 31st and is awaiting reviews.
- Submitted the journal paper "Financing Solutions for Circular Business Models" to Business Strategy and the Environment. The paper was submitted on April 1st and is awaiting reviews.

For the practitioner audience, the project results have been presented for different audiences on – at least – the following occasions:

- Presentation on *Finanssektorns roll i omställning till cirkulära modeller* at Almi Halland, ESG-nätverksmöte, on 19th November 2020.
- Participated in the Nordea Xynteo Sustainable banking week in November 2020.
- Presentation on *Cirkulär ekonomi – Framtidens tillväxt* for business advisors at Danske Bank, 10th of February 2021.
- Presented at World Circular Economy Forum Side event, in a seminar on *Financing Circularity, Institutional investors and ESG*, held on the 29th June 2021. This event was organized as part of the CircularNext, North America 2021 series, with a global audience.
- Recorded a training session about CE, CBM and Circular financing for Nordea's global on-line training program, in September 2021.
- Conducted a training session for the leasing experts at Nordea Finance in October 2021.
- Published a story about AI and financial risk "Hur bedöms finansiell risk av en circular affärsmodell?" at ri.se. Published in December 2021.
- Interviewed for the daily publication Computer Sweden, resulting in an article about the project "Hur mycket är en begagnad vara värd? Nu kan en AI ge svaret." Published in January 2022.
- Conducted a webinar with more than 100 participants, on the 8th of March 2022, where we presented the project results and organized three PaaS case presentations and a panel discussion with four representatives from the bank and finance sector.
- Packaging of the 13 solutions in a pop-science format in Swedish and English, including packaging for two different audiences (PaaS companies and Financiers). These results have been broadly disseminated and communicated via LinkedIn.
- We have published the AI model as open source at https://github.com/edvinli/AI-CBM
- This final report.

The project web site is updated with all the results from the project, including a recording from the webinar. It will also be updated with the coming papers, when they are published.

Project Results

Residual value, Risk assessments & Business Ecosystems

The challenge

From our project we can conclude that the challenge of financing product-as-a-service models is real. It is particularly difficult for small and medium sized firms in the stage of scaling. The faster the scaling, the bigger the problem. The challenges are related to the two of the three risk assessment categories that banks (and other financiers) use to assess credit risk. The two risk assessment categories are Asset/collateral-based and Business case-based, see figure 2.

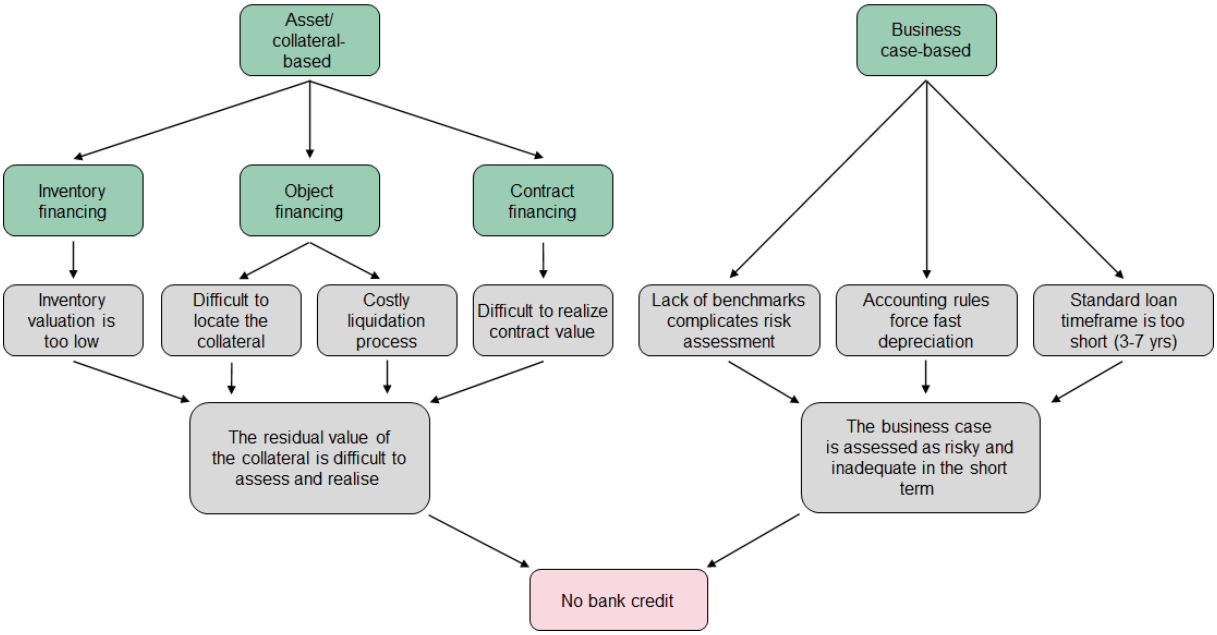

Figure 2. The disadvantage of PaaS-based CBMs, for different credit risk assessment categories

A product firm seeking bank financing for a PaaS CBM needs to convince the bank regarding the suitability of the available collateral and business case as securities for the loan. One option is inventory financing, a type of collateral-based security. However, for inventory financing de facto regulations (GAAP) severely limit allowed valuations of the products and force almost immediate depreciation and payback of the loan.

The next option is object financing, relying on potential realisation value (market price) of the collateral, as commonly used for cars. Here the bank will commonly balk at the potential cost of collection of the PaaS CBM collateral. For instance, the lack of government freely provided unique object identifiers such as vehicle registration numbers. If collectability seems likely, the bank will estimate the cost of liquidation. However, bank industry practice is to estimate that as a cost per item, making it seem prohibitively costly for large fleets of low value products such as electronics, furniture, or clothes.

Not giving up hope, the prospective debtor firm might at this point turn to its long list of secured and legally bound-to-pay customers, attempting to use the contracts as collateral. However, the

contracts are only valuable as collateral if they can be sold to another firm with the capability of delivering the agreed product-service offering. This leads to a catch-22 situation. Until a circular economy transition has already occurred through the diffusion of PaaS CBM, such contracts will not enable financing of PaaS CBM, which will in turn be at a competitive disadvantage in terms of financing.

As collateral will not function as security for a bank loan, the product company and bank explore the business case of the PaaS CBM as security for the loan. The starting point for the bank is to assess reasonable benchmarks or reference values, such as competitors and historical financial numbers. This again leads to a catch-22. Until a circular economy transition has already occurred through the diffusion of PaaS CBM, there will not be benchmarks to enable financing of PaaS CBM, which will in turn be at a competitive disadvantage in terms of financing.

At this point it may be challenging to get the bank to consider financial projections as a security, but that is the next logical step. Assuming such projections look very profitable indeed, the bank will upon closer scrutiny point out that the main cost advantage in a PaaS CBM – the minimal value depreciation of the product fleet – is highly unconventional from an accounting practice perspective. Many banks (and their auditors) are more comfortable with following convention when it comes to accounting practices.

Finally, if the bank for some reason considers the risk acceptable there remains the final challenge of payback schedule. It is banking industry practice to expect payback for such loans within 3 – 7 years. Thus, if the PaaS CBM is successful enough in terms of product life, its product fleet will remain underfinanced after a few years even in the best of cases with a hypothetically very risk-accepting bank.

Future financing business ecosystem

Our results from the interviews and the survey as well as discussions at a workshop focused on future business models and ecosystems confirmed the challenges and highlight opportunities and potential solutions for financing CBMs and the effect on roles and actors in the business ecosystem. Figure 3 visualizes the flow of goods and information in an illustrative B2C PaaS case where the ownership of the products can be exchanged between the product company, financial actors, and customers/users.

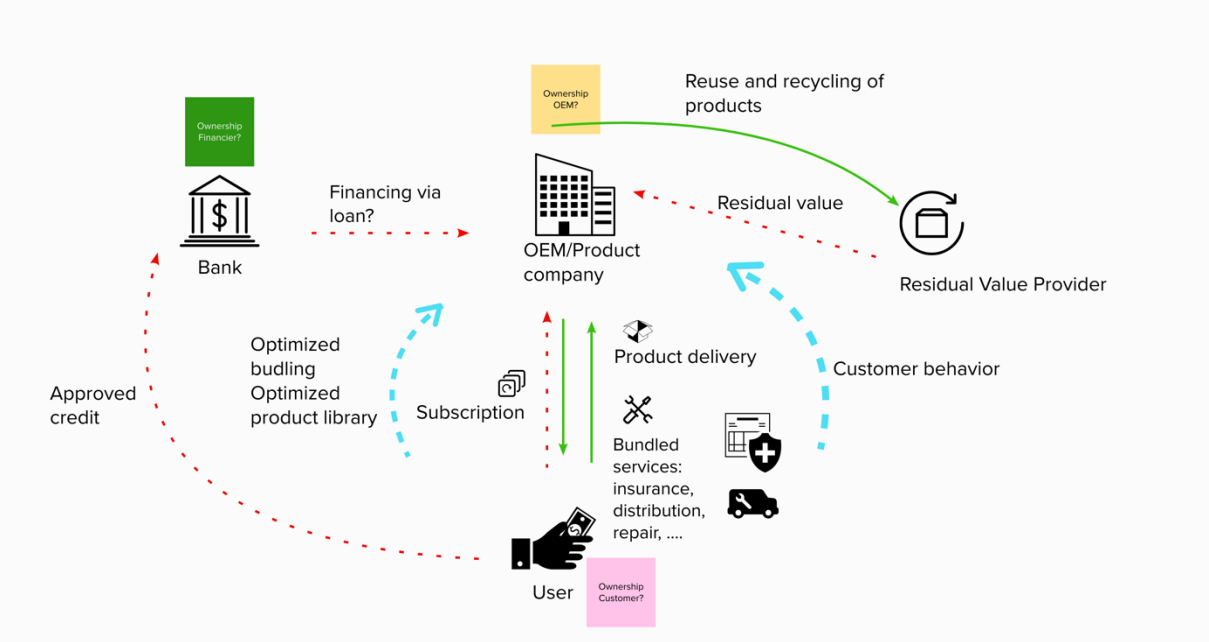

Figure 3. An illustration of a PaaS-based business ecosystem

Based on our results, there is an array of different PaaS scenarios, including both subscription models, long- and short-term rentals and functional and performance sales. The types of companies that operate (and want to operate) PaaS business models are very different from each other (for example in terms of size and planned speed of scaling), as are the products and services involved. In summary, the PaaS space is heterogenous, which implies that **financing solutions also need to be varied, flexible and adaptive.**

The survey showed that the companies that struggle the most with financing were companies that want to scale relatively low-valued product, such as clothes and sports articles, and/or products that are new in the PaaS space and that do not have established second-hand markets, such as cameras, lighting and aquaponics equipment.

Our findings further indicate that a number of different financial actors already play a role in financing of these circular business models. Venture capital, business angels and other types of owner capital, as well as leasing and specialized financing firms have important roles to play, depending on the type of PaaS firm and product. Moreover, banks play an important part in the financing mix. Banks are more regulated than other types of financial actors, and thereby limited in terms of risk taking. Banks are also considered as stable and strong, and as such often a preferred partner for companies in a scale-up situation. When bringing more unusual type of financing partners from the business ecosystem into the equation, **banks could play a mediating, stabilizing and term-setting role.**

We identify and categorize our results on financial solutions and opportunities for PaaS-based CBMs into 13 solutions categorized into three groups:

1) asset-/collateral-based, where the asset (product or contract) used as collateral can be liquidated by the financier in case of default of the product company, and the residual value thus realized.

2) business-case-based, where the loan repayment capacity of the product company is assessed through future business projections.

3) relationship-based, where the trustworthiness of the team behind the business is assessed, together with its collaboration partners.

The solutions

The following 13 solutions to the challenges described above have been identified:

1. Future adaptive design
2. Lease-back
3. Build an aftermarket
4. Contract financing
5. Lease on lease
6. Step-for-step loans
7. Include risks of linear business models in the profitability analysis
8. Stable revenue flows
9. Reduce risk with controlled growth
10. Show positive LTV/CAC ratio
11. Customer financing
12. Long term partnerships and niched actors
13. Industry specific key partners

Deliverables

Three academic papers.

- "Financing solutions in Future Circular Business Ecosystems" at the ISPIM conference, held in Berlin on the 21st - 23rd June 2021.
- "Financing of Circular Business Models: The case of Product-as-a-service"
- "Financing Solutions for Circular Business Models"

Six different "solution packages" in power point-format, see Appendix 1:

- 13 solutions for PaaS models – Swedish
- 13 solutions for PaaS models – English
- Solutions for PaaS companies - Swedish
- Solutions for PaaS companies – English
- Solutions for financiers - Swedish
- Solutions for financiers – English

AI model and Programme

In figure 4 below an illustration of the proposed AI model is shown. We use a pre-trained vision model and a pre-trained Swedish language model to create representations of the auction images and texts, respectively. These are concatenated and fed into a multi-layered perceptron which is trained to predict the end price.

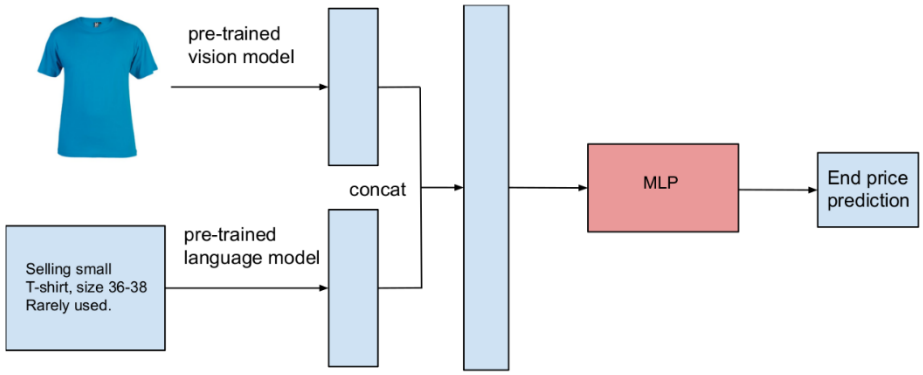

Figure 4. Principle of AI model

We modelled the problem both as a regression problem and a classification problem, see report in Appendix 2 for detailed discussion. In figure 5 below we show results for the classification task, where each auction item is categorized into one out of nine price classes. The plot shows the error of the model, i.e. the difference between the true price class and the by the model predicted price class. We see that the most common error is zero, meaning that the model makes a correct prediction. Further, we note that when the model makes an erroneous prediction it still is closer to the true price class, meaning that the model tends not to overshoot too much.

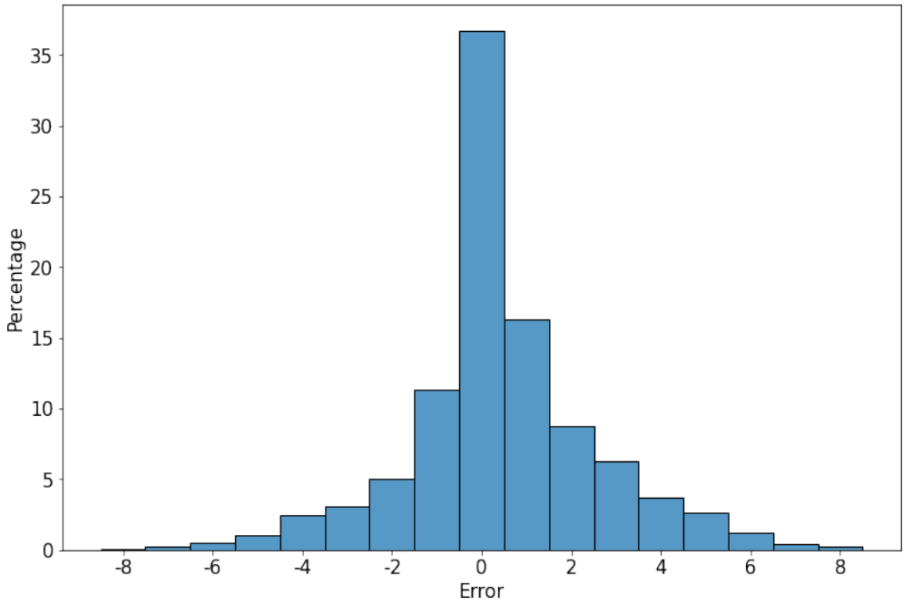

Figure 5. Model price class error (true – predicted)

Table 1 below shows the accuracy and top 2 accuracy for different AI models with different input representations. Here it can be seen that just using image representation, an accuracy on 30.25% can be achieved. We can increasingly get better performance by also using text representations, where bigram representations in combination with pre-trained image representations achieved the best results. We refer to the report (in Appendix 2) for more discussion.

Model	Representation	Accuracy	Top 2 accuracy
MLP	Clip image	30.25	47.56
MLP	Clip text	32.83	51.80
MLP	Clip text + image	33.86	53.06
Logistic reg	Unigram	34.33	53.46
Logistic reg	Bigram	36.08	56.03
MLP	Bigram	36.96	57.63
MLP	**Bigram + clip image**	**37.2**	**57.77**

Table 1. AI model results per type of model

Figure 6 shows the result from the human evaluation of the problem. Here, we created a form consisting of 10 random images from the test set (no text descriptions, making the

problem harder). This form was sent out to and answered by 32 humans, with the question asked being "What do you think the end price of this auction was?". The question was posed as a multiple-choice question, with the nine price classes as possible answers.

The results for each human can be seen in figure 9 in blue. This can be compared to the deep learning model only using image representations as inputs (orange). The mean human accuracy was 18.75% on these 10 images, whereas the model achieved 40%. Only two humans got the same accuracy as the model, and only one human beat it. We also see that seven humans got a score of 0%.

Further note that by using majority voting of the human answers an accuracy of 10% was achieved, not better than random chance. These results indicate how hard the problem is, and that the deep learning model is able to quite well estimate the value of second-hand items as compared to humans.

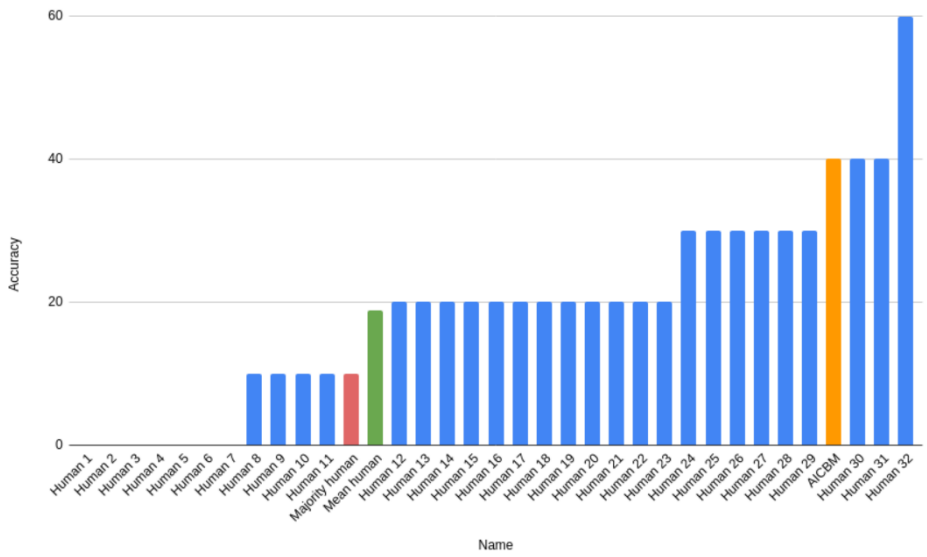

Figure 6. Accuracy for humans (blue), mean human (green) and AI model (orange). Accuracy based on majority human voting shown in red.

Deliverables

One academic paper.

- "Residual value prediction using deep learning for circular economy" submitted to SIGKDD 2022.

The results of the AI work have also been consolidated and documented in report format, see Appendix 2, and the AI model has been published as open source at https://github.com/edvinli/AI-CBM

Discussion

There is an array of different PaaS scenarios, including both subscription models, long- and short-term rentals and functional and performance sales. The types of companies that operate (and want to operate) PaaS business models are diverse and different from each other (for example in terms of size and planned speed of scaling), as are the products and services involved, implying that there is a need for a varied set of financing solutions.

Earlier studies have listed the challenges of financing such PasS-based CBMs (Linder et al, 2022) as well as the solution strategies (Toxopeus et al, 2021) along the lines of the lending technologies used by financiers, grouping them in Asset-/collateral-based, Business case-based and Relationship-based. We position our findings in line with these three categories and further both confirm earlier research on challenges (Adams et al., 2017; Kirchherr et al., 2018; Govindan & Hasanagic, 2018; Vermunt et al., 2019; Tura et al, 2019; Grafström & Aasma, 2021) and add more concrete solution suggestions:

The asset-based solutions we propose include product design for value retention, actively building an aftermarket for your products and services, using contracts as collateral and using credit products, such as leaseback, lease-on-lease and stepwise loans. **The business case-based solutions** proposed include making direct comparisons with the linear model over a relevant period of time to show the advantage of the circular business case, stressing the linear risk and the high-quality revenue projections of the circular case. In addition to this, the growth rate might need to be controlled so that profitability can be made visible, and a more opportunistic approach is to convince the financier of future profitability through the so-called CAC/LTV ratio. We also **suggest relationship-based solutions**, emphasizing the relationship between the PaaS-company and the financier, but also pointing at risk sharing with customers through prepayments and crowdfunding, as well as with actors in the supply chain. A truly deep understanding of a customer segment might develop into industry-specific financial actors. Involving other actors that can provide repair and refurbishing services as well as the realization of the residual value of the product, will also help providing trustworthiness in your case towards the financier.

Further, we have shown that it is possible to some extent to predict auction end prices for categories clothing. Our results show that image representations of auction items can be used to train a small neural network to model the residual value. Together with text representations from CLIP, the performance can be boosted. However, in the end the simplicity of only using unigram and bigram representations gave the best results, combined with the image representations. This is a promising result, indicating that AI-predictions could be used to better assess risk in asset- or collateral based risk assessment scenarios. An objective value calculated by an AI-model could be used to strengthen the arguments for both asset-based and business case-based assessments, since they would potentially be more trustworthy than manually estimated values.

These suggested solutions for financing of CBMs sometimes overlap, and they can be combined with each other. The solutions are focused on how to solve the need for bank credit when scaling PaaS models. Depending on the situation and development phase of the PaaS firm, financing solutions could of course also include equity investments and different forms of venture capital, especially in earlier phases. It is also possible to solve some of the challenges of transitioning an existing linear company to a PaaS-based business through placing the circular business in a separate business unit or even company. This could enable the use of more precise and suitable key figures and financial ratios for the benchmark of business cases. Our conclusion is, however, that at some point in the

scaling of the PaaS business, whether a start-up or an existing company, bank credit will be a necessary prerequisite for most companies.

While residual value and the possibility to realize collateral through the liquidation of the asset used as security is one of the key aspects of credit assessment frameworks today, it should be noted that in a future more circular world, where the value of products is retained for as long as possible, it is possible – even likely – that there will be no aftermarket for products in PaaS-based CBMs. The products will be kept by the PaaS provider and deliver value for a very long time, until they can no longer be used for their purpose, and need to move into a less value-preserving circular loop such as recycling. This means that residual value as a concept will become less important. This will also possibly blur the lines between the two credit assessment categories, asset-based and business-case based. For the time being, however, it seems likely that solutions trying to predict residual value in an objective way, such as the AI-model in our study – and asset-based credit assessment in general - is an important enabler for the circular transition through PaaS CBMs.

Conclusion and Recommendations

This study extends the short body of empirical literature on managing transition to CBMs by paying particular attention to innovations needed in financial risk assessment and financial instruments for CBMs. Our investigations are one of the first to attend to the cross-section of CBMs, business ecosystems, finance, and digital technologies by discussing the future of circular business ecosystems and the nature of collaborations required between incumbents and financial actors when moving from mainly linear to innovative CBMs.

This paper provides Circular Economy practitioners with recommendations and insights related to potentials and challenges for financing CBMs and sheds light on how AI modelling can be incorporated in financial risk assessment. Understanding what alternative financial solutions in new circular business ecosystems could look like will in turn decrease the perceived uncertainties and risks associated with practice of Circular Economy and can accelerate the transition towards CBMs.

Theoretical contributions

This article makes theoretical contributions to the literature on CBMs, sustainable finance and servitization in the following ways:

First, our results contribute to CBM literature by particularly responding to previous literature highlighting financial barriers to CBM when firms transition from product-based to service-based business models. We provide empirical solutions for sustainable financing of CBMs from multiple stakeholders' viewpoint by focusing on both product companies and financial actors needs and uncertainties. The fifteen financial solutions provide concrete examples for how the circular financing strategies suggested by Toxopeus et al (2021) can be implemented by product companies and financial actors.

Second, we show how application of cutting-edge digital technologies such as AI can facilitate modelling the residual value of products and thereby calculating financial risks in circular economy. The experimental model developed in the article makes a novel and hand-on contribution to our understanding of the importance of cross-section of digital technologies and circular economy previously highlighted in the CBM literature (Ellen McArthur Foundation, 2019; Chauhan et al., 2022).

Managerial implications

For the PaaS-company, our research results have some important practical implications. Firstly, the business case-based financial solutions indicated above, are all directed towards the PaaS-company, giving them hands-on tips on how to present and package the circular business case in the dialogue with potential financial partners. The asset-based solution on future and modular product design also indicates the importance of combining product and business model design both for optimal circular results and for addressing the risk averse financier. Solutions pointing at the need for new types of relationships also give an indication to the PaaS-company of the importance of establishing and developing networks and relationships beyond the traditional ones, e. g. to help establishing value retention through repair and refurbishment partners and to establish residual value points and aftermarkets, through more collaborations with – potentially competitive – actors in the same sector.

Our AI results indicate that there are potential AI-based solutions to tackle financing based on "hard-to-value" assets. And if residual value predictions are combined with monitoring and predicting

customer, contract and payment data, there is an opportunity for a "risk monitor", that could potentially strengthen both the internal management decisions and the dialogue with the financier. Moreover, AI modelling of residual value can be used for other purposes than financial assessment. The quality of production and materials used in the product (offered for sale or as a service) is of crucial value also for strategic decision making in terms of product and business model design decisions, e. g. identifying frequent points of failures of a product may give invaluable signals to improve the value retention of products.

For the bank, this study points at several concrete solutions to be able to take on the financing challenge of CBMs. The suggested list of credit instruments (leaseback, lease-on-lease and stepwise loans) in the asset-based solutions, points at opportunities that might not be new, but still seem under-explored and under-used in relation to CBMs. Moreover, the suggested relationships-based solutions have strong implications for banks and other financiers, since they go beyond the normal bank–company relationships of today, involving both closer collaboration and deeper business understanding, but also involving other partners that have the potential to share the risk burden. This is a huge opportunity for learning and business development for the bank and might even develop into realization of new financing instruments and vehicles to better serve the financing market for PaaS CBMs.

Further our results indicate that a machine learning model is a much better predictor of residual values of used clothing than human beings. This is an important result, since collateral-based risk assessments based on residual values is still important for banks, and if those residual values were assessed by a machine instead of a human being, they could be considered more neutral, trustworthy and valid. Moreover, the possibility for an AI model to also assess "time before sell" could further decrease the risks associated with taking over inventory/assets in case of default.

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Appendix

1 Financial Solutions

See separate file.

2 AI model detailed results

See separate file.