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Towards a post-irrevocable payment undertaking era: Dynamic credit limits in supply chain finance

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ABSTRACT

Supply Chain Finance (SCF) arrangements often rely on irrevocable payment undertakings to protect investors from dilution risk. However, many buyers are either unable or unwilling to provide such guarantees, which limits access to financing for many suppliers. We study a novel alternative SCF arrangement: a Dynamic Credit Limit (DCL) arrangement that operates without an irrevocable undertaking. This arrangement determines real-time funding eligibility for suppliers based on past transaction data, dilution history, supplier and buyer risk, and billing behavior. Using transaction data from *The Interface Financial Group*, one of the first providers to implement DCLs at scale, we compare its performance with that of invoice financing. DCL provides significantly more funding while reducing the probability and severity of loss. We examine the underlying algorithm, evaluate its empirical effectiveness, and demonstrate that this approach enables an inclusive, scalable SCF even in the absence of buyer guarantees.

1. Introduction

Supply Chain Finance (SCF) enables companies to strengthen their supply chains (Wuttke et al., 2013b; Liu et al., 2022; Liao et al., 2025). Companies like Siemens,[1] Walmart,[2] and Michelin[3] offer SCF programs to their suppliers to enhance their own working capital, secure critical supplies, and ensure their suppliers are paid early. Central to those examples, buyers approve invoices from their suppliers and commit to an irrevocable payment undertaking (IPU) (an unconditional promise to pay[4]). These undertakings eliminate dilution risks for finance providers—the risk that suppliers are not paid by buyers in full due to chargebacks, set-offs, or counterclaims. Without dilution risks, finance providers' risks are reduced to the buyer's credit risk, and providers can offer financing to suppliers at low interest rates (van der Vliet et al., 2015; Gelsomino et al., 2016; Liu et al., 2022).

However, not all buyers are eligible for IPU-based SCF programs, which are generally limited to investment-grade buyers: fewer than 7,000 globally,[5] compared to over 309 million businesses worldwide.[6] Even eligible buyers may prefer to retain the option to withhold payment in case of defects or fraud (Lee and Stowe, 1993; Summers and Wilson, 2003; Babich and Tang, 2012). As a result, many suppliers remain excluded from SCF and must rely on more expensive and constrained alternatives such as invoice financing, which fewer than 10% of small and medium-sized enterprises can access, and often only at limited volumes.

In this study, we define SCF as a set of financial arrangements involving at least two supply chain firms and a third-party finance provider. Whereas IPU-based approaches are among the most popular SCF arrangements in industry, SCF is broader. Specifically, this study examines a novel buyer-led non-IPU-based SCF arrangement called a *Dynamic Credit Limit (DCL)*. We study the case of *The Interface Financial Group*, which was the first to offer DCL at a large scale. At the core of this approach is the question of how SCF providers can protect against dilution risks without invoking IPUs. The provider we study retains a portion of the approved invoices as a buffer (first recourse basis). For

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[4] https://iccwbo.org/news-publications/policies-reports/position-paper-on-irrevocable-payment-undertakings-ipus/, accessed on 2025-06-08.
[5] https://www.spglobal.com/ratings/en/research/articles/241003-credit-trends-global-state-of-play-strong-issuance-fuels-debt-growth-13270349, accessed on 04/17/2025.
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instance, for an invoice portfolio of $1 mn, the provider might advance $900k and keep $100k as a reserve. If that reserve is exhausted, the provider draws on future payments from the same buyer to the same supplier (second recourse basis). In this example, those might sum up to $350k. As a final fallback, the provider may seek recovery from the supplier's payments by other buyers or even collect from the supplier (third recourse basis). In this example, this happens if the dilution exceeds the reserve of $100k and the future payments of $350k. By design, these recourse bases are meant to strike a good balance of funding provision and risk mitigation.

If the effectiveness of the DCL method were demonstrated empirically, it could potentially guide Supply Chain Finance into a post-irrevocable payment undertaking era, substantially expanding the scope of supplier financing. However, its effectiveness has yet to be shown. And so, our paper answers the following questions: Does DCL work? How does it perform in terms of funding provision and risk mitigation? How do investors compute appropriate credit limits in practice?

Using 32,536 DCL transaction records, we conduct a statistical analysis to compare DCL with invoice financing, the most viable alternative available to many suppliers excluded from SCF programs. We then examine the core logic of the DCL algorithm and study the data requirements for its implementation.

Analyzing historical transactions, we find that the DCL arrangement enables finance providers to fund significantly and substantially more supply chain transactions while simultaneously lowering the finance providers' risk exposures. When matching the level of funding, invoice financing would have exceeded the first recourse basis 90% more often than DCL. Only 84 transactions (0.26%) in the DCL sample exceeded the second recourse basis, requiring escalation to collection. In contrast, our counterfactual shows that 450 transactions (1.38%) would have been escalated under invoice financing, which is a statistically and economically meaningful difference.

As a result of the in-depth study of the implemented DCL approach, we find that it is a sophisticated algorithm that dynamically calculates credit limits by integrating multiple risk dimensions. It balances funding extension with risk mitigation by evaluating historical invoice adjustments, payment irregularities, and supplier billing patterns, while also incorporating a comprehensive supplier risk score. This layered recourse structure, comprising invoice-level buffers, buyer–supplier payment history, and supplier viability, enables the provider to adjust credit limits in real-time, effectively managing dilution risks without relying on irrevocable payment undertakings. Our exploration of the algorithm reveals its practical capability to allocate credit efficiently and adaptively, supporting larger funding volumes while controlling risk exposure. At the same time, we recognize that a digitally integrated platform is necessary to build upon real-time data.

We conclude that the DCL is a viable option for buyers seeking to facilitate financing to their suppliers without committing to irrevocable payment undertakings.

2. Literature review

Our work builds on and expands the Supply Chain Finance literature (for recent reviews, see Xu et al., 2018; Chen et al., 2020a). Most closely related are studies on financial arrangements where buyers facilitate early payments to suppliers based on irrevocable payment undertakings. Notably, a practice often referred to as reverse factoring is such an arrangement (van der Vliet et al., 2015; Kouvelis and Xu, 2021). Under reverse factoring, buyers confirm approved invoices to a third party (e.g., a bank or Supply Chain Finance provider). Based upon that confirmation, they are obligated to pay the full amount on the scheduled payment date.

In industry, reverse factoring is among the most relevant forms of supply chain financing, with an estimated global market of over $2.4 trillion (Bickers, 2025). As one might expect, research has studied various aspects of reverse factoring (see Gelsomino et al., 2016; Wetzel and Hofmann, 2019, for excellent reviews). Tanrisever et al. (2012), Lekkakos and Serrano (2016), Grueter and Wuttke (2017), and Kouvelis and Xu (2021) examine how reverse factoring adds value. Wuttke et al. (2013a) and Liebl et al. (2016) study adoption and buyer motives using case studies; Wuttke et al. (2016) study optimal adoption decisions analytically. Wuttke (2025) shows how buyers benefit from reverse factoring by extending payment terms. Dello Iacono et al. (2015), Wuttke et al. (2019), de Goeij et al. (2021), and Banerjee et al. (2021) examine adoption from the supplier's perspective. These studies indicate that reverse factoring can add substantial value to supply chains, but it is not a one-size-fits-all solution. While many highlight the importance of the irrevocable payment undertaking, none of the above papers propose alternatives that operate without such a commitment.

However, research also shows that buyers may be reluctant to commit to irrevocable payment undertakings because doing so eliminates their ability to withhold (or dilute) payments to suppliers. Buyers may use the time between shipment and payment to thoroughly inspect the quality and reduce sourcing risks (Lee and Stowe, 1993; Tang, 2006). As Summers and Wilson (2003) observe, this delay motivates suppliers to signal confidence in product quality by waiting for payment. Buyers may also use deferred payments to address concerns such as adulteration (see Babich and Tang (2012) and Tang and Babich (2014)). Furthermore, buyers might discover underperformance across earlier deliveries and use the outstanding payment as a set-off. When buyers commit to irrevocable payment undertakings but later detect issues such as incompleteness, defects, or fraud, they must pursue costly chargebacks or off-system settlements outside of regular accounts payable processes.

Other SCF studies examine financing arrangements that do not require irrevocable payment undertakings. Tunca and Zhu (2017) study buyer intermediation in supplier financing, where buyers facilitate supplier loans even before contractual performance. As an alternative, buyers may use buyer-direct financing, avoiding intermediaries altogether (Wu, 2024; Chen et al., 2020b). Reindorp et al. (2018), Wu (2017) and Wu (2024) analyze buyer-backed purchase order financing, where suppliers obtain financing based on confirmed purchase orders, and buyers may assume part of the performance risk through payment guarantees. While these arrangements do not involve irrevocable undertakings, they often expose buyers to even greater risks and are typically used for select strategic suppliers on a case-by-case basis.

We study a financing arrangement that neither requires an irrevocable payment undertaking nor a buyer's guarantee before production. Instead, this approach offers funding to a broad set of underfinanced suppliers based on approved invoices and real-time data, while maintaining buyer flexibility.

Recent studies shed light on how digitalization and alternative financing mechanisms can broaden the scope of Supply Chain Finance. Analytical and empirical work demonstrate that cash-constrained firms can utilize trade credit, dynamic pricing, and loan-payment timing to mitigate financing frictions (Raghavan and Mishra, 2011; Priya et al., 2023; Yang and Liu, 2023). Technology-centric contributions demonstrate that blockchain and e-commerce platforms reshape channel selection and pricing decisions for capital-constrained suppliers (Dong et al., 2023b,a; Sriraman et al., 2025). Meanwhile, big-data analytics capabilities and a data-driven culture foster deeper integration of Supply Chain Finance within manufacturing firms (Yu et al., 2021). From an ecosystem perspective, third-party platforms orchestrate inter-organizational networks to scale Supply Chain Finance services (Li et al., 2022; Zhang et al., 2025). Capital-constrained manufacturers weigh crowdfunding, bank, and supplier finance options when launching new products (Chen et al., 2022). Collectively, these studies suggest that digital tools and innovative structures can expand access to financing for partners previously excluded from traditional IPU-based programs. The method discussed in this study draws on the idea of incorporating digital

Table 1
Summary of methods related to financing supply chain transactions.

Method	Risk mitigation strategy	Availability
IPU-based reverse factoring	Advances funding for outstanding approved/confirmed invoices and based on the creditworthy buyers' unconditional promise to pay, to mitigate dilution risks through irrevocable payment undertakings (IPUs)	Available only for investment-grade and near investment-grade buyers
Dynamic discounting	Uses buyers' own funds to pay suppliers early in exchange for a discount	Only feasible for buyers with consistent extra liquidity
Receivable Finance, Factoring	Advances funding for outstanding verified invoices (not approved yet) based on buyers/suppliers' creditworthiness	Available for suppliers' invoices with verifiable deliverables and a lower advance rate against eligible AR
Asset-based lending (ABL)	Line of credit with a dynamic borrowing base based on accounts receivable as collateral, depending on AR quality and supplier creditworthiness	Only suitable for larger suppliers and solely based on the supplier creditworthiness and eligible AR
Dynamic credit limits (DCL)	Advances funding based on outstanding approved invoices and historical buyer–supplier pairs repayment patterns	Available for sub-investment grade buyers as well

technologies into Supply Chain Finance, as it builds on a platform that collects data in real-time.

Finally, our study draws from finance research outside of SCF. First, finance literature emphasizes the importance of managing credit risks. In credit-related transactions, such as those found in commercial lending, financiers largely consider credit scores, reflecting common industry practices (Altman, 1980). This is relevant as financing periods in commercial lending are often long-term. However, it is important to note that credit risks are extreme events, where firms are unable to repay their debt. In contrast, dilution risks in supply chains are far more common. Dilutions occur every time a buyer does not pay an invoice in full, which happens for many legitimate reasons (e.g., incomplete delivery, quality issues, or chargebacks), not only because of a bankruptcy. Additionally, financial transactions in supply chain finance differ from commercial lending as they have a short financing horizon of a few weeks or months. Second, the finance literature explores other established forms of receivables-based financing, such as factoring (Klapper, 2006), receivables financing (Saulnier and Jacoby, 1943; Ulrich, 1978), and invoice financing (Pavlov et al., 2004; Powell, 2016). In these schemes, the supply chain plays a minor role; buyers neither confirm nor are necessarily aware that their suppliers use invoices as collateral. According to our definition, those arrangements do not involve two or more supply chain parties and would thus not be considered SCF. This lack of buyer involvement is more than a semantic issue: it introduces risks for lenders, including dilution, delayed payments, or fraud. In the arrangement we study, by contrast, the buyer enables the finance provider to view approved invoices and scheduled payment dates. However, the buyer does not unconditionally promise to pay the invoice in full.

Table 1 provides a summary of extant approaches and positions DCL. The first column states methods that are regularly applied in industry. The second column summarizes their risk mitigation strategies. Each strategy affects the availability of funding, as seen in the last column.

3. Problem setting

This section outlines the empirical setting. We study the case of *The Interface Financial Group (IFG)*. This company began its innovative transactional invoice finance business in 1972 and has since transformed it into an industrial-grade, fully digital Supply Chain Finance platform, serving global buyers and suppliers in early payment markets. Throughout this discussion, we refer to our case company as the *SCF provider*, because this arrangement can apply to multiple providers.

The DCL method addresses a significant issue in invoice financing, specifically the *dilution risk*. Dilution risks concern approved and scheduled for payment invoices. To understand the risk management approach of *The Interface Financial Group (IFG)*, it is insightful to understand the economic problem and causes of dilutions better.

Dilutions for approved invoices typically occur when the buyer has legitimate reasons not to pay the full amount (e.g., due to quantity or quality issues) or when suppliers owe money to buyers, allowing buyers to settle the difference by issuing debit entries and not paying the full invoice amount. For instance, the buyer provides some service to the supplier, and instead of separately billing the supplier for this service, cross-settles the payment against the supplier's invoices; this happens regularly. Therefore, dilutions are common in the day-to-day business.

So, to be clear, the dilution risk is a day-to-day risk, as opposed to credit risks or defaults, which are very rare events. Buyers may daily dilute some invoices for good reasons. But they tend to file for bankruptcy very rarely. Still, technically, a bankruptcy of a buyer could also lead to a dilution.

The DCL program is buyer-led, meaning that buyers initiate and set up the program. Buyers use the program to strengthen their upstream supply chain without committing to an irrevocable payment undertaking, either because they cannot or do not wish to make such a commitment. Suppliers join the program to obtain more funding than they would under invoice financing and at lower costs. Participation in the DCL program requires a one-session click-through sign-up registration process, during which the provider ensures compliance with regulatory requirements, including anti-money laundering, know-your-customer, and anti-terrorism measures. Due to the efficiency, even small businesses can join the program. To be efficient, the DCL program is fully automated and runs on a digital platform that integrates into procurement, accounts payable automation platforms, and the buyers' ERP systems.

Fig. 1 describes the typical timeline and major events in trade transactions that follow the Dynamic Credit Limit (DCL) financial arrangement.

At t_1, the supplier fulfills contractual obligations by shipping products or delivering services and issues an invoice to the buyer. At t_2, the buyer approves the invoice.[7] From t_2 to t_3, the supplier has not

[7] It is helpful for our discussion to know what various invoice statuses mean and how some of them have associated dilutions and early payment options. Some invoice statuses, such as submitted, voided, approved, or rejected, are standard and easy to understand; however, we will clarify here more thoroughly the statuses relevant to our topic. Once a supplier issues an invoice to a buyer upon delivery of goods, completion of work, or provision of services, the invoice attains the "submitted" status. After an invoice is submitted and when investigating factoring, invoice discounting, or accounts receivable (AR) financing to enable early payments, financing providers verify the invoice's validity by confirming deliverables have been met, upgrading the status to "verified", and potentially rendering it eligible for invoice-financing transactions. Most setoffs and other dilutions tied to invoice deliverables arise between the verification and approval steps. This is called pre-approval dilution. An invoice's status is upgraded to "approved" once the buyer formally approves it for a scheduled payment, qualifying it for Supply Chain Finance (SCF) programs. Post-approval dilutions occur less frequently, but they still

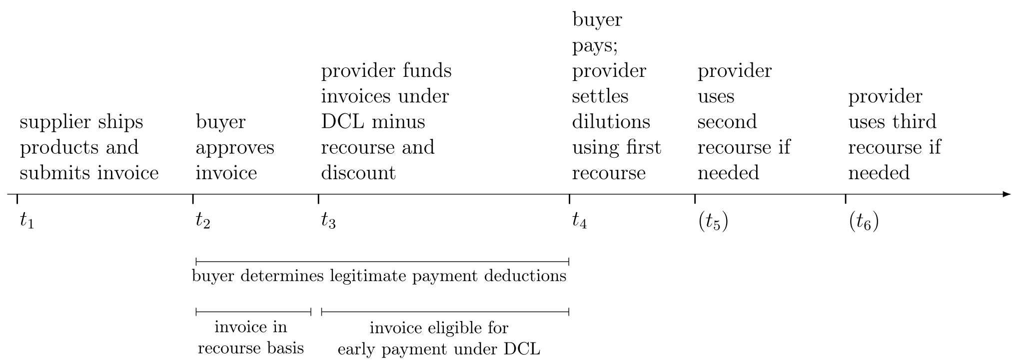

Fig. 1. Timeline.

requested funding on this invoice, and this invoice can be used as a recourse on other invoices (see discussion in Section 1). As of t_3, the invoice is eligible for early payment under DCL. The SCF provider establishes a dynamic credit limit and provides early payment to the supplier for requested invoices. We offer a detailed description of the dynamic credit limit calculation in Section 5.

The DCL method differs from conventional commercial lending in that it does not involve principal and interest. Specifically, the provider is purchasing invoices from the supplier at a discount. This constitutes the purchase/sale of the assets and technically does not involve lending with principal and interest. The discount is like a fee that the provider charges. Thus, we can think of it as an interest, because discount allows to project return as annualized yield, but there is technically no interest payment, and the term "interest" is not commonly used in industry in this context (for example, in reverse factoring or dynamic discounting, it is more common to discuss a discount rate rather than an interest rate). Therefore, in Fig. 1, we note that at t_3, the provider funds invoices under the DCL method in the amount of the total invoice value minus recourse and discount.

At t_4, the buyer's payment to the supplier is made. During the period from t_2 to t_4, the buyer determines legitimate post-approval payment deductions. Several mechanisms influence payment amounts. Notably, setoffs allow buyers to offset payments against amounts owed by suppliers, promoting settlement between them. Chargebacks occur due to fraud, unsatisfactory goods, or services. Therefore, the amount the buyer pays at t_4 is the diluted amount. Typically, the DCL is below the supplier's total approved invoice portfolio value, with the difference forming the provider's first recourse basis. The supplier can obtain financing up to the DCL, and the provider secures a claim on the invoice equivalent to the funded amount.

If the supplier maintains an outstanding balance with the provider after t_4, the provider anticipates future invoices from the same buyer to the same supplier (labeled as time t_5 on the figure; the actual date is unknown, which is indicated and thus marked as (t_5)). Those constitute the second recourse basis. Because the DCL method incorporates additional invoices into the DCL calculation and supplier funding, both buyer and supplier are motivated to submit and approve all outstanding invoices.

At some future time t_6 (also unknown), if even payments on future invoices are insufficient, the provider uses the third recourse basis or a collection process. In that case, the provider considers invoices that the supplier has issued to other buyers as collateral or escalates the matter into collection. However, this recourse form may incur high administrative and legal costs.

Overall, from a provider's perspective, the first recourse basis comes with the least cost to the provider. The second recourse is riskier because it depends on the payment of future invoices; however, it is low-cost because the transactions are handled automatically. The third recourse basis is both uncertain (in terms of amount and timing) and expensive.

3.1. DCL technology requirements

We will next discuss the underlying technologies that enable the efficient use of the DCL method. This method requires integration capabilities with data sources, either via the REST API, the SOAP API, or the XML API, as real-time data push and pull operations are necessary across numerous data points. The technology is typically hosted securely in the cloud and may utilize platforms such as AWS, Google Cloud, Azure, Oracle Cloud, or other environments. A range of database types can be employed. For instance, a company may utilize an AWS PostgreSQL database, Python, and REST API integration, among other technologies. Servers and application code must deliver performance sufficient to calculate dynamic credit limits within 15–25 ms. Sensitive data must also be encrypted at all times. Technically, blockchain and IoT can also be used for implementing DCL; however, they are not currently utilized by the IFG and are not strictly required.

4. Empirical investigation of DCL performance

This section examines the effectiveness of the DCL arrangement empirically. We begin by describing the dataset provided by *The Interface Financial Group*.

4.1. Data

The dataset covers all observations and transactions considered under DCL for a 10-year period, resulting in 32,536 observations. The data features 826 suppliers, transacting with 24 buyers. These buyers and suppliers primarily operate in the Western Hemisphere, encompassing the United States, Canada, the United Kingdom, Europe, and Australia. There are also some suppliers based in China, India, Vietnam, and Hong Kong. Table 2 provides summary statistics for transaction-related variables used in evaluating the performance of the DCL method below.

The variable *Approved AR* presents the value of the approved accounts receivable of the 32,536 underlying transactions. The maximum of 3.6 million USD indicates that sizable invoices also obtain funding under DCL. The variable *Dynamic Credit Limit* represents the percentage of the Approved AR that is eligible for funding. The average of 0.905 indicates that suppliers obtained funding for about 90.5% of

pose a significant risk to the finance provider. Importantly, dilution risk differs from late payment risk (cf. Kong et al., 2024), as diluted invoices are still paid on time, but not fully. The role of IPUs is to remove the risk of post-approval dilution. A further invoice status "confirmed" is important for the IPU process, and this is where the buyer confirms to the SCF provider the invoice's validity and their intention to remit the scheduled payment in full. Without IPU or confirmed invoices, dilution leads to the SCF provider's loss. This article focuses on invoices that are not yet confirmed but have reached the approved status, and describes the method for mitigating dilution risk.

Table 2
Summary statistics for transaction-related variables.

Variable name	min.	max.	Median	Mean	std. dev.	Count
Approved AR (mn. USD)	0.000	3.614	0.064	0.176	0.274	32,536
Dynamic credit limit (%)	0.467	1.000	0.919	0.905	0.070	32,536
Invoices Funded (mn. USD)	0.000	3.482	0.058	0.160	0.250	32,536
Paid (mn. USD)	0.000	3.482	0.056	0.159	0.251	32,536
Dilutions/Approved AR	0.000	0.929	0.000	0.031	0.096	32,536
Dilutions/Invoices Funded	0.000	0.996	0.000	0.038	0.117	32,536
Supplier credit score	6.000	100.000	97.000	90.375	14.029	32,536
Buyer-specific ceiling C_b	0.650	1.000	0.927	0.917	0.059	32,536

Note: Monetary values are expressed in millions of USD where indicated. All values are rounded to three decimal places. The minimum values for both Approved AR and Invoices Funded exceed zero but appear as zero due to rounding conventions.

the accounts receivable. The DCL method, as presented in Section 5, produces this percentage. The variable *Invoices Funded* captures the dollar value corresponding to the dynamic credit limit. The variable *Paid* then shows the amount the buyers paid to the Supply Chain Finance provider. The difference between this amount and the Invoices Funded is the dilutions. The variable *Dilutions/Approved AR* establishes a relationship between dilutions and approved receivables; the variable *Dilutions/Invoices Funded* does so for the ratio with funded invoices. The mean of 0.038 indicates that, on average, 3.8% of the amount on invoices funded was diluted. Those needed to be recovered using the first, second, or third level of recourse. We present those in the next section, comparing them with a counterfactual comparison.

4.2. Performance of the DCL financing arrangement

This section addresses our main research question: Does DCL work? Specifically, we assess the benefits and risks of the provider when using DCL, relative to viable alternatives available to the suppliers in our dataset.

As we discussed in the introduction, the most effective financing alternative to DCL would involve financing under irrevocable payment undertakings. However, this option is unavailable to the suppliers in our sample. Without DCL, they would either receive no financing or, at best, receive traditional invoice financing. The DCL method is clearly superior to the no-financing scenario. To construct a more conservative comparison, we compare the DCL arrangement to classical invoice financing.

To that end, we simulate a counterfactual in which a finance provider offers traditional invoice financing. We consider invoice financing, where the funder applies a fixed recourse. This fixed-recourse approach is commonly used in industry (Klapper, 2006). It is important to distinguish that recourse provisions operate across both recourse-based and non-recourse-based invoice financing structures. In the latter case, although the finance provider formally accepts the buyer's credit and insolvency risk (events that occur infrequently) recourse mechanisms remain fully operative with respect to all other dilution factors affecting the receivables. The funder bears substantial risks in invoice financing, leading to substantial recourse (Constand et al., 1991). On average, many funders advance only 60% of the accounts receivable value. In invoice financing, this percentage is fixed by the funder across invoices of the same supplier and across different suppliers; we thus refer to it as the "*Flat X*" method, where X refers to the percentage of funding of accounts receivable provided. So, "Flat 60%" relates to a typical ratio of funding provided against a supplier's total accounts receivable (including eligible and ineligible AR for funding).

As seen in the literature review (Section 2), SCF differs from commercial lending as bankruptcy and credit risk events play a minor role. Still, one might expect that funders could use corporate credit scores of suppliers to determine the advance rates. If so, they would not use a flat method, but one that uses such credit scores. Although this approach is rather uncommon in industry, we also consider it a benchmark to demonstrate the robustness of our analysis and to emphasize that it is essential to include a broader set of parameters, as the DCL method does (see Section 5).[8]

Comparing financing schemes, however, is non-trivial, as finance providers typically face a trade-off between two important dimensions. On the one hand, they seek to provide as much liquidity as possible. Offering more funding increases business and generates more revenue. Moreover, the market for early payment solutions is competitive; acquiring new customers is challenging, and therefore, the ability to offer more funding to existing customers is valuable. On the other hand, investors must manage risks. Generally, there is no straightforward way to combine both variables into a single quantity. Therefore, we compare financing schemes along both dimensions: funding provided and risk.

A further complication arises due to the various levels of recourse, which translates into various types of risks. The first recourse basis is optimal from a risk perspective: as long as dilutions are below the recourse, there is no harm for investors. However, there is some risk when dilutions exceed the first recourse basis. There is even more risk when exceeding the second recourse basis. There is, likewise, no simple map to compare these three risks. Therefore, we consider them separately in our analysis, starting with the risk of exceeding the first recourse basis.

4.2.1. Funding provided and the risk of exceeding the first recourse basis

We begin the comparison of the DCL method with a counterfactual of invoice financing by examining funding provided and the risk measured as the probability of exceeding the first recourse basis or Value at Risk (VaR) or Conditional Value at Risk (CVaR). We evaluate all metrics in two dimensions — the financing available to suppliers and risks of the provider — and adopt a concept akin to an efficient frontier. A method is considered more efficient if it offers (i) lower risk for the same level of financing and (ii) more financing for the same level of risk. Under this logic, if one method dominates another, it does so regardless of investors' risk appetite.

For performance evaluation with VaR and CVaR metrics, we focus on cases where dilution exceeds the first recourse basis and quantify the resulting exposure (loss = dilution − recourse) using 95%-Value-at-Risk (95%-VaR) and 95%-Conditional Value-at-Risk (95%-CVaR) conditional on observing dilutions. Both VaR and CVaR are commonly-used risk metrics in practice (for definitions and discussion, see Szegö (2002), Koenig and Meissner (2015) and Babich and Birge (2021)). The

[8] One reason why funders often use flat methods is that they are easy to administer and that credit scores are seen as insufficient predictors for dilutions. To put this into perspective, consider our dataset. On average, over a five-year rolling horizon, 99.8% of suppliers have witnessed at least one dilution. In stark contrast, corporate defaults, i.e., credit risk events, are extremely rare. In 2024, 0.0% of the firms with S&P ratings of AAA, AA, and A defaulted; only 0.05% of firms with a credit rating of BBB did (Serino et al., 2025). So clearly, other predictors for dilutions are more powerful. Since funders often lack these, they regularly prefer a flat method that provides sufficient recourse. In contrast, the DCL method aims to account for the broad spectrum of predictors, as described in Section 5.

Table 3
Performance comparison of credit allocation methods.

Method	Avg. financing as % of AR	Pr[Dilution > Recourse]	95%-VaR Cond. on dilution	95%-CVaR Cond. on dilution
DCL	90.52%	5.05%	34.83%	50.59%
Flat 90.52%	90.52% (0.00%)	9.60% (+90.26%)	42.70% (+22.59%)	54.28% (+7.30%)
Flat 90%	90.00% (–0.57%)	9.23% (+82.83%)	42.19% (+21.10%)	53.76% (+6.27%)
Flat 80%	80.00% (–11.62%)	4.99% (–1.16%)	32.19% (–7.61%)	43.76% (–13.50%)
Flat 70%	70.00% (–22.67%)	3.08% (–39.04%)	22.19% (–36.31%)	33.76% (–33.26%)
Flat 60%	60.00% (–33.72%)	2.03% (–59.81%)	12.19% (–65.02%)	23.76% (–53.03%)
Flat 50%	50.00% (–44.76%)	1.25% (–75.15%)	2.19% (–93.73%)	13.76% (–72.80%)
CS (abs)	88.54% (–2.18%)	8.99% (+78.20%)	40.89% (+17.38%)	53.02% (+4.81%)
CS	76.10% (–15.93%)	6.50% (+28.87%)	33.06% (–5.10%)	46.32% (–8.44%)

Note: Percentage changes relative to the DCL method values are in parentheses. CS (abs) (i.e., credit score absolute) method provides advance rates of 60% to suppliers with credit scores less than 30, 75% to suppliers with scores at least 30 but less than 70, and 90% to suppliers with scores at least 70. CS method allocates advance rates of 60%, 75%, and 90% using the 33rd and 66th percentiles of the supplier credit score distribution.

95%-VaR corresponds to the threshold for the worst 5% of dilution-over-recourse cases. The 95%-CVaR is the average of the worst 5% of dilution-over-recourse losses.

Table 3 compares the DCL arrangement to a range of flat-percentage comparisons. As explained above, each flat method releases a fixed share of the approved AR, irrespective of buyer or supplier characteristics. This rate is also referred to as the *advance rate*. For example, the "Flat 90%" method makes 90% of AR available (i.e., it advances 90%), leaving 10% for recourse. Because the average DCL arrangement yields an average advance rate of 90.52% in our sample, we include "Flat 90.52%" for direct comparison. The "Flat 60%" method corresponds to the manual risk-based invoice financing commonly used in practice, which we introduced earlier.

As alluded to above, one can argue that a more sophisticated approach would be to account for the supplier's credit risk. In the CS (abs) (i.e., Credit Score absolute) method, we have categorized all transactions into three groups based on suppliers' Corporate Credit Score in absolute terms: Group 1 includes suppliers with scores less than 30, Group 2 comprises those with scores greater than 30 but less than 70, and Group 3 consists of suppliers with scores above 70. In the same way prudent invoice finance practitioners would, we chose advance rates of 60 percent for Group 1, 75 percent for Group 2, and 90 percent for Group 3. The CS method allocates advance rates of 60%, 75%, and 90% using the 33rd and 66th percentiles of the supplier credit score distribution.

Columns 2–5 of Table 3 show the average financing offered, the probability that dilution exceeds recourse (i.e., Pr[Dilution > Recourse]), the 95%-VaR, and the corresponding CVaR. Percentage changes relative to the DCL method values are in parentheses. For example, the "Flat 90.52%" method provides the same financing level as DCL, but risk increases markedly: dilution exceeds recourse in 9.60% of cases (vs. 5.05% for DCL), with 23% higher VaR and 7% higher CVaR. The "Flat X" methods for $X \leq 80\%$ reduce risk but offer less financing relative to the DCL method.

Our analysis of the CS (abs) method indicates that this counterfactual results in less average funding provided (−2.18%) than the DCL method, but requires invoices to be escalated to the second level of recourse in 2925 cases (8.99% of all cases). This is substantially worse than the DCL method, which required such escalation in only 1643 cases (5.05%), roughly half as often. The CS method results in −15.93% of funding relative to the DCL method, but +28.87% more escalations to the second level of recourse. This suggests that, although a credit-stratified approach may seem more reasonable than a flat rate, it does not resolve the issue.

Table 4
Comparison of Pr[Dilution > Recourse] under DCL and Flat 90.52% methods with classical z-test of proportions. Statistics are two-tailed, $N = 32{,}536$, $^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Event	DCL [%]	Flat [%]	Difference	z-statistic
DCL < Flat 90.52%	5.05	9.60	4.55	22.3^{***}

Fig. 2 provides the efficiency frontier for "Flat X" methods (blue curve). In this figure, the preferred position is in the lower right corner, and the DCL method clearly dominates the efficiency frontier of the "Flat X" methods.

Based on Table 3 and Fig. 2, the CS and CS (abs) methods are Pareto-dominated by some of the "Flat X" methods (e.g., "Flat 88.54%" method). In turn, the DCL method Pareto-dominates the "Flat X" methods. Therefore, DCL also Pareto-dominates the CS and CS (abs) methods. This highlights the importance of accounting for a variety of buyer–supplier characteristics as the DCL method does.

Finally, to test whether the differences are statistically significant, we applied a classical test of proportions on the probability of dilutions exceeding the first recourse. To keep the level of funding fixed, we compare the differences between the DCL arrangement and the "Flat 90.52%" method. Table 4 provides the estimates, confirming that the difference is also statistically significant.

4.2.2. *Funding provided and the risk of exceeding the second recourse basis*

We now turn to the risk of exceeding the second recourse basis. Recall from Section 3 that the second recourse involves drawing on future invoices from the same buyer; the third recourse involves invoices to other buyers or collections, which are costlier and less predictable. And so, this section analyzes the risk of having to invoke the third recourse basis.

We compare the DCL method to the "Flat 90.52%" method so that we keep the average advance rates fixed among both methods. From the previous section, we know that the "Flat 90.52%" method leads 90.26% more often to the necessity of evoking the second recourse basis. In this section, we examine whether this also translates into invoking the third

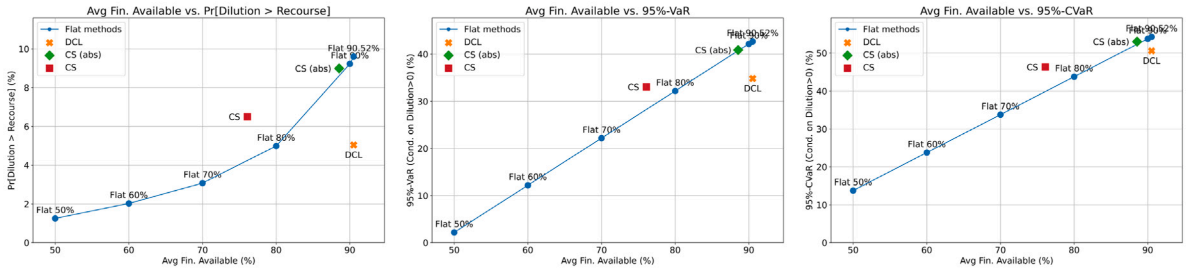

Fig. 2. Financing vs. dilution risk: DCL vs. alternative methods.

Table 5
Comparison of escalation rates to the third level of recourse under DCL and Flat 90.52% methods with classical and Wilson/Agresti-adjusted z-tests. Statistics are two-tailed, $N = 32{,}536$, $^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Method	Event	DCL [%]	Flat [%]	Difference	z-statistic
Classical	DCL < Flat 90.52%	0.26	1.38	1.13	15.90***
Wilson-adjusted	DCL < Flat 90.52%	0.26	1.38	1.13	15.87***

recourse more often, which happens when the second recourse basis is insufficient.

Turning to the results, under DCL, only 84 out of 32,536 transactions (0.26%) required escalation to the third level of recourse. In contrast, the "Flat 90.52%" method required escalation in 450 transactions (1.38%). This represents a relative increase of 436%.

The escalation beyond the second recourse level means that future invoices issued by the supplier and scheduled for payment by the buyer are insufficient to cover the difference between the funded invoice amount and the diluted payment. To mitigate potential losses, the provider can use the third level of recourse by collecting proceeds from invoices issued to other account debtors/buyers of the supplier. This process is not automatic and requires significant effort on the part of the SCF provider for collection.

Table 5 presents the results of tests of statistical difference. The first row presents a classical two-proportion z-test, the second row shows a Wilson/Agresti-adjusted test. The Wilson/Agresti test is more appropriate for rare events. For a discussion of this adjustment, see Wilson (1927), Agresti and Coull (1998) and Brown et al. (2001). Both tests find that the differences in the proportions are not only economically relevant but also statistically significant.

So, when providing the same level of funding (advance rate of 90.52% of accounts receivable), invoice financing would require 110.25% more escalations to the second recourse level than the DCL method does. Invoice financing requires even 431% more escalations to the third level. Both increases are statistically significant. These findings demonstrate that the DCL method effectively and substantially reduces the risk for investors relative to invoice financing.

5. Dynamic credit limit (DCL) algorithm

This section outlines the DCL approach implemented by *The Interface Financial Group*, which resulted in the estimates shown in Section 4. It documents a concrete and implementable algorithm that balances two competing goals: extending funding and mitigating risk exposure.

Consider the perspective of a provider offering early payments to suppliers based on approved invoices from buyers, but without the security of an irrevocable payment undertaking. In such a setting, effective funding decisions must account for multiple dimensions of risk. These include the buyer's likelihood of full payment, the presence of historical patterns indicative of payment dilution, and the supplier's operational continuity and capacity to generate future receivables. The DCL algorithm systematically incorporates these considerations, translating diverse and evolving risk signals into a real-time credit allocation framework.

Fig. 3 illustrates the overall structure of the DCL calculation. It provides the key variables and required information that we shall discuss next. In that discussion, we will indicate how those factors directly map into the three levels of recourse bases.

At its core, the dynamic credit limit for buyer b and supplier s is given by

$$DCL_{bs} = \max\left\{\left(\sum_{n=1}^{N} I_a(n)\right) C_b H_{bs} M_s,\ 0\right\}, \tag{1}$$

where $I_a(n)$ denotes the value of approved invoice n, N is the number of approved invoices, C_b is a buyer-specific ceiling set by the provider, H_{bs} reflects expected dilution based on historical buyer–supplier interactions, and M_s adjusts for the supplier's forward-looking viability. The outer maximum ensures that credit is withheld if risk exceeds acceptable limits (the first term in the maximum becomes negative in certain cases, as discussed below). As shown in the figure, C_b is a parameter that discounts the maximum funding extended for risky buyers. This parameter is recalibrated monthly by the finance provider. In contrast, H_{bs} and M_s are dyadic and dynamic; they can be further factorized. The former (H_{bs}) captures expected recoveries from approved invoices for a buyer–supplier dyad bs; the latter (M_s) adjusts for the likelihood of continued supplier performance.

The remainder of this section presents the formulas for H_{bs} and M_s, along with their logic. This discussion follows the structure shown in Fig. 3, moving from left to right and bottom-up: we start with invoice- and payment-level dilution analysis, proceed to billing regularity, and then construct a comprehensive supplier risk score.

5.1. Historical-dilution multiplier H_{bs}

The historical dilution multiplier, H_{bs}, captures how much of the approved invoice value the provider expects to recover, on average; it directly translates into the first and second recourse basis: if buyers have a history of paying the full amount (or close to the full amount), the same can be expected to happen in the future. If, in addition, suppliers tend to bill the buyer regularly, there is a strong second recourse basis.

The historical dilution multiplier consists of three components:

$$H_{bs} = M_i \cdot M_p \cdot M_d$$

where M_i reflects invoice-specific reductions after approval, M_p reflects payment-level deductions not tied to specific invoices (both related to the first recourse basis), and M_d captures how consistently the supplier invoices over time (related to the second recourse basis).

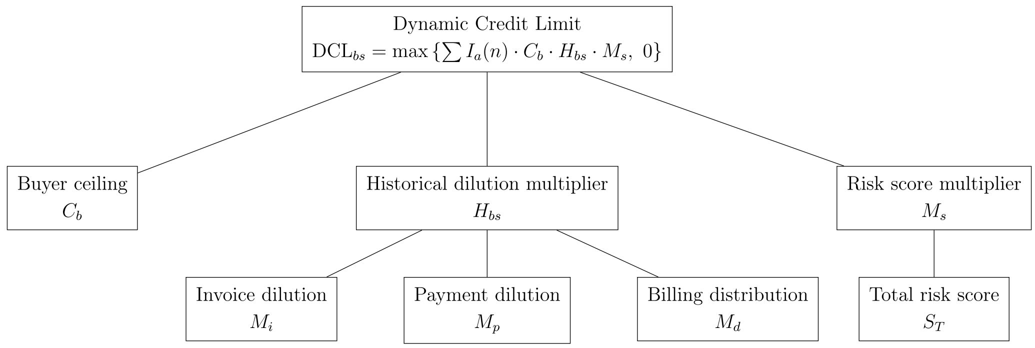

Fig. 3. Conceptual calculation of DCL.

To see how these play out, consider a supplier who regularly ships boxes of pens. In one case, the buyer reduces an approved invoice after discovering product issues—this is invoice dilution, which feeds into M_i. In another, the buyer accepts the goods but deducts unrelated charges (e.g., for online advertising for that supplier) during payment—this is payment dilution, captured by M_p. If the supplier ships every week in similar volumes, the provider can rely on future receivables to recover shortfalls; if shipments are erratic, this fallback is riskier. That variation is reflected in M_d. Each component is computed using six rolling 30-day windows (i.e., a 180-day lookback).

The *invoice dilution multiplier*, M_i, is defined as $M_i := 1 - R_i$, where R_i is the reserve that the provider sets aside to buffer against invoice-level dilution risk. This reserve increases with the observed invoice dilution ratio r_d, which measures the expected shortfall on approved invoices due to buyer-side adjustments.

To estimate r_d, the provider analyzes invoice-level data over the past 180 days. For each invoice n, it calculates $\Delta_I(n)$ as the reduction between the initially approved and final amount paid. The ratio r_d aggregates these adjustments relative to invoice size and adjusts for volatility:

$$r_d = \frac{\mathrm{avg}(\Delta_I(n))}{\mathrm{avg}(I_a(n))} + A_1 \cdot \frac{\sigma(\Delta_I(n))}{\mathrm{avg}(I_a(n))}.$$

Here, $\mathrm{avg}(\cdot)$ and $\sigma(\cdot)$ denote the sample mean and standard deviation, respectively. The parameter $A_1 \geq 0$ controls the weight placed on uncertainty. In Section 5.3, we provide typical values for each parameter, like for A_1.

The reserve R_i is then computed as a piecewise function of r_d, reflecting a non-linear response to growing risk:

$$R_i = \begin{cases} k_1 \cdot \dfrac{r_d^2}{L_1^2}, & \text{if } r_d < L_1 \\ k_1 + \dfrac{r_d - L_1}{L_2 - L_1}(k_2 - k_1), & \text{if } L_1 \leq r_d < L_2 \\ k_2 + \sqrt{\dfrac{r_d - L_2}{L_3 - L_2}}(1 - k_2), & \text{if } L_2 \leq r_d < L_3 \\ 1, & \text{if } L_3 \leq r_d < 1. \end{cases}$$

This functional form captures distinct risk dynamics. When dilution is minimal ($r_d < L_1$), reserve requirements increase quadratically, resulting in only small penalties. As dilution enters a moderate range ($L_1 \leq r_d < L_2$), the reserve grows linearly, reflecting more consistent underpayment risk. Beyond L_3, full reserve is required. The thresholds and parameters are calibrated to reflect portfolio-level risk preferences (see Section 5.3). So, the resulting multiplier M_i discounts the provider's exposure to each invoice by the empirically estimated dilution risk and buffers accordingly.

The *payment dilution multiplier*, M_p, is defined as $M_p := 1 - R_p$, where R_p is a reserve accounting for reductions that occur at the time of payment but are not linked to specific invoices. These include buyer-initiated debit entries such as penalties, offsets, or service charges, which can lower the overall amount remitted even if no issues arise with individual invoices.

To estimate this reserve, the provider analyzes the past 180 days, divided into six consecutive 30-day periods. For each period, it records two quantities: I_A, the total value of invoices scheduled for payment, and I_E, the total value of debit entries recorded by the buyer.

The reserve is then calculated as:

$$R_p := \frac{\mathrm{avg}(I_E) + A_2 \cdot \sigma(I_E)}{\mathrm{avg}(I_A)},$$

where $\mathrm{avg}(\cdot)$ and $\sigma(\cdot)$ denote the mean and standard deviation across the six periods. The parameter A_2 introduces an adjustment for volatility in debit behavior. This adjustment is required because, as with invoice dilution, the reserve increases when the buyer regularly imposes significant or erratic deductions. So, the resulting multiplier M_p reduces funding exposure accordingly, capturing dilution risks that materialize during payment processing but remain invisible at the invoice level.

The *historical billing distribution component multiplier*, M_d, is defined as

$$M_d := B_1 - (B_1 - B_2) \cdot \frac{\sigma(I_m)}{k_3 \cdot \max(I_m)},$$

where I_m is the total invoice volume in each of six 30-day periods covering the past 180 days. This component reflects the idea that if a supplier issues invoices at a regular pace and in consistent amounts, future billing can serve as a reliable fallback for absorbing shortfalls. In contrast, erratic billing behavior makes recovery less predictable and reduces the multiplier.

The term $\sigma(I_m)$ measures the variation in invoice volumes, and the denominator $k_3 \cdot \max(I_m)$ scales it to a plausible upper bound. This normalization ensures that the resulting ratio remains within the range of 0 to 1. To derive that bound, we apply Popoviciu's inequality on variances.

Suppose $I_m(j) \in [m, M]$ for $j = 1, \ldots, n$. Popoviciu's inequality (Popoviciu, 1965) states that:

$$\frac{1}{n}\sum_{j=1}^{n}\left(I_m(j) - \mathrm{avg}(I_m)\right)^2 \leq \frac{1}{4}(M - m)^2,$$

which provides a bound on the population variance of any real-valued distribution limited to the interval $[m, M]$. Using the definition of the sample standard deviation, we rewrite:

$$\sigma^2(I_m) = \frac{1}{n-1}\sum_{j=1}^{n}\left(I_m(j) - \mathrm{avg}(I_m)\right)^2.$$

Substituting the inequality and simplifying:

$$\sigma(I_m) \leq \frac{1}{2}\sqrt{\frac{n}{n-1}}(M - m) = k_3(M - m),$$

where $k_3 = \frac{1}{2}\sqrt{\frac{n}{n-1}}$. In our application, we set the lower bound $m = 0$, so the maximum possible standard deviation becomes $k_3 \cdot \max(I_m)$.[9]

The parameters B_1 and B_2 define the upper and lower bounds of the multiplier. A supplier with perfectly stable billing (zero standard deviation) receives a bonus score of B_1. As variation increases, the score smoothly drops toward B_2. This dynamically discounts the DCL for volatile suppliers while modestly rewarding those who exhibit operational consistency.

5.2. Risk-score multiplier $\boldsymbol{M}_s$

The risk score multiplier M_s reflects whether the supplier is likely to remain eligible, operational, and capable of issuing future invoices. This protects the provider when fallback mechanisms depend on incoming receivables. And so, this multiplier is mainly important for the second and third recourse basis.

The multiplier is determined through a composite risk score $S_T \in [0, 100]$ and a bracketed mapping:

$$M_s = \begin{cases} M_j & \text{if } T_j \le S_T < T_{j-1} \quad \text{for } j \in \mathcal{J} \\ 0 & \text{if } S_T < T_4 \end{cases}$$

where the index set $\mathcal{J} = \{0, \ldots, N\}$ defines the scoring intervals, with $T_0 = 100$ and descending thresholds $T_1, \ldots, T_N$ marking the breakpoints. Each interval corresponds to a risk multiplier $M_j \in [0, 1]$ used to adjust the DCL.

In the implementation that we study, the total score S_T aggregates six dimensions:

$$S_T = \frac{\sum_{i=1}^{6} S_i W_i}{\sum_{i=1}^{6} W_i}$$

Here, $S_1, \ldots, S_6$ represent ratings on: business credit, fraud or threat, compliance, liens or encumbrances, financial standing, and internal performance. Each score $S_i \in [0, 100]$ under normal conditions. If a supplier violates a critical requirement (e.g., is not in good standing), then the score for M_s is overridden with 0, preventing the supplier from obtaining any financing. The weights $W_1, \ldots, W_6$ determine the relative importance of the six criteria. These are calibrated by the provider and may be adjusted based on data availability, compliance emphasis, or market conditions.

Conceptually, the idea of building composite scores rather than using single-item measures to assess risks is related to previous work. For instance, Paudyn (2025) and Doumpos and Figueira (2019) also use composite risk scores, albeit in a different financing context.

Fig. 4 illustrates the six constructs that contribute to the total risk score. This figure further decomposes each into a subcategory level. The DCL method calculates the score for each construct by considering its subcategories. This illustration demonstrates the variety of indicators that inform the supplier risk assessment.

Finally, note that the discussion so far has not explicitly emphasized the liquidity aspects captured by the DCL. Still, this method accounts for various liquidity aspects directly and indirectly. Most importantly, payment cycles are accounted for by design. To be precise, buyers often deviate from payment terms and pay suppliers late, a well-known phenomenon. However, this risk does not affect the DCL method, as it only extends financing for invoices that are scheduled to be paid. Whether or not this date aligns with the payment terms is irrelevant. So, when buyers schedule an invoice for payment, they must ensure that they have sufficient liquidity. In the rare cases where this does not occur, the DCL method would count this as a 100% dilution, resulting in an escalation to the next level. Furthermore, alongside the buyer's historic risk multiplier update, the ceiling parameter C_b is reduced if a buyer's credit risk increases, resulting in substantially lower advance rates for future invoices with that buyer.

5.3. Parameterization in industry

The DCL algorithm, as implemented by *The Interface Financial Group*, relies on a set of parameters that reflect experience-based tuning, proprietary judgment, plausible risk responses, and operational feasibility. Table 6 summarizes the key parameters and their typical values. These fall into several categories. First, volatility weights such as A_1 and A_2 amplify the impact of unpredictable behavior in invoice-level and payment-level dilution calculations. Second, the reserve function for invoice dilution is governed by a piecewise construction with thresholds L_1, L_2, and L_3 and values k_1, k_2. This structure imposes soft penalties for low dilution but ramps up reserves sharply for higher-risk profiles.

Third, the multiplier for billing regularity is bounded by B_1 and B_2 and scaled using the factor k_3, which is derived from Popoviciu's inequality and reflects the maximal dispersion possible over six intervals (Popoviciu, 1965). This ensures comparability and boundedness in evaluating the supplier's historical consistency.

Fourth, the supplier risk score, S_T, is mapped into the multiplier, M_s, using tier thresholds T_0 through T_4 and associated values M_1 through M_4. This provides a piecewise mapping from a composite score into a multiplier used in the DCL. The score itself is a weighted average of six dimensions, with weights W_1 through W_6 capturing the relative importance of creditworthiness, fraud potential, compliance, liens, financial standing, and internal history.

Using the dataset described in Section 4.1, we graphed implicit relationships between average financing available and providers' risk metrics under the DCL method, as key parameters of the DCL algorithm change: A_1, A_2, B_1, B_2, k_1, k_2, k_3, L_1, and L_2.[10] These graphs (shown in Figs. 5 and 6) indicate that the current parameter values are efficient, in the sense that one cannot Pareto-achieve a lower risk for the provider and higher financing for suppliers by changing parameter values. Consistent with this observation, minimizing the provider's risk metrics using the above parameters as decision variables, subject to the constraint of maintaining the same level of average financing for suppliers, does not yield better parameter values than the current ones.

6. Conclusion

This study examines a novel financing approach for supply chains that operate without irrevocable payment undertakings. By analyzing the design and real-world performance of Dynamic Credit Limits (DCLs), we demonstrate that Supply Chain Finance can be extended to buyers who are unable or unwilling to guarantee full invoice payments. Using proprietary transaction data from *The Interface Financial Group*,

[9] We adopt Popoviciu's inequality rather than Chebyshev's inequality (or its generalizations) or parametric normal assumptions because it provides an *upper bound* on the variance for a bounded random variable. Conceptually, it asks: what is the largest possible variance for any distribution supported on a finite interval? The answer is, according to Popoviciu's inequality, that the maximum is achieved by a two-point distribution with probability mass at the endpoints of the interval. This is opposed to the normal distribution, which allocates mass around the mean and has unbounded support.

Formally, Popoviciu's inequality states that for any random variable X supported on the interval $[a, b]$,

$$\mathrm{Var}[X] \le \frac{(b-a)^2}{4},$$

with equality if and only if $\Pr[X = a] = \Pr[X = b] = 1/2$ (Popoviciu, 1965). Therefore, Popoviciu's inequality provides the exact upper bound we require.

In contrast, Chebyshev-type inequalities (including Markov's and the generalized Chebyshev inequality) provide *lower bounds* on the variance, linking it to the probability of large deviations.

[10] The dataset does not have observations that would trigger DCL conditions corresponding to parameter L_3. Therefore, the corresponding graphs are omitted.

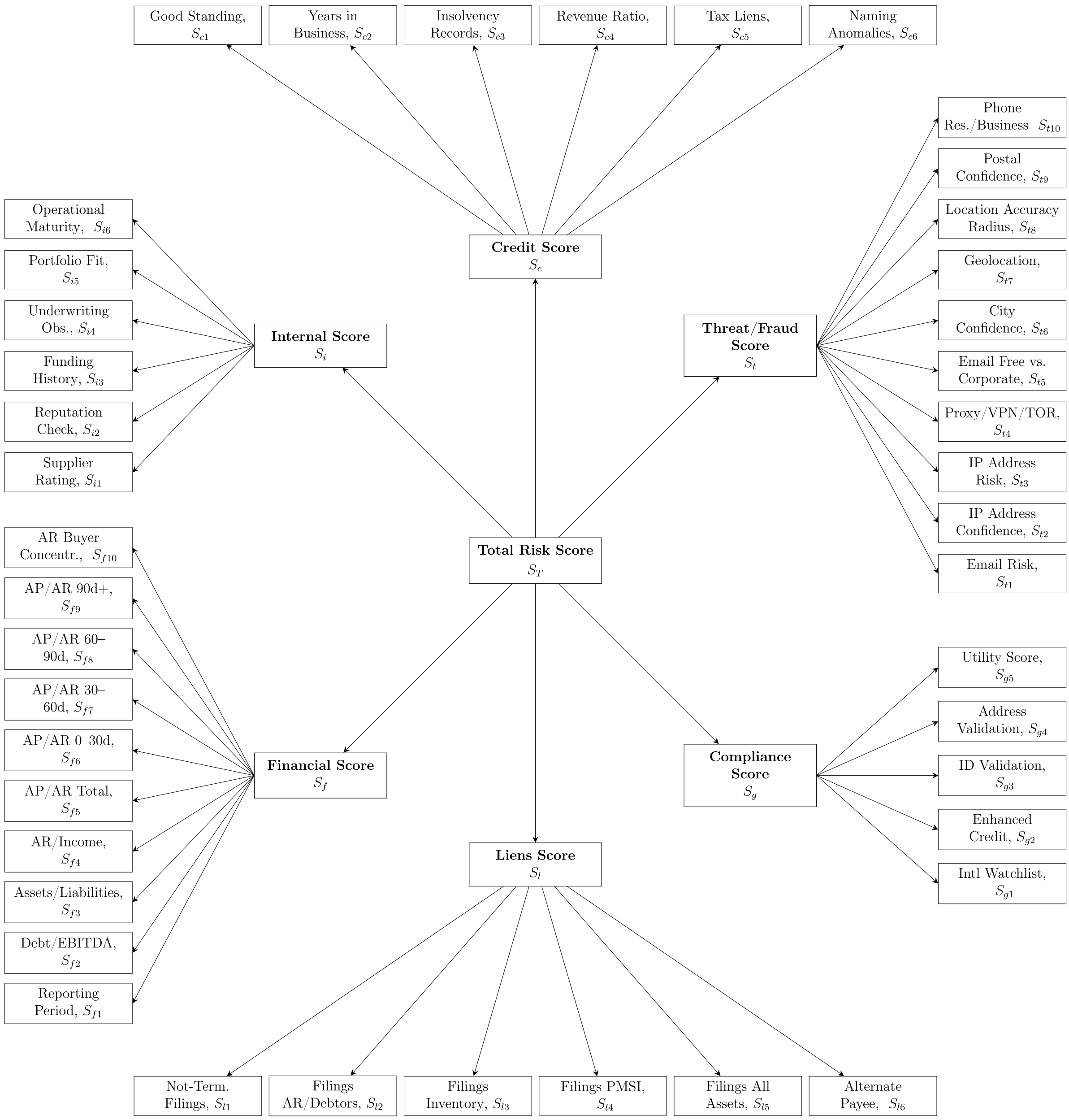

Fig. 4. Total risk score composition.

Table 6
Parameter definitions and typical values in DCL algorithm.

Name	Symbol	Definition	Typical value
Volatility weight in invoice dilution	A_1	Emphasizes variance in invoice dilution ratio	0.03
Volatility weight in payment dilution	A_2	Emphasizes variance in payment-level deductions	0.1
Invoice dilution threshold (low)	L_1	Lower threshold for quadratic reserve growth	0.003
Invoice dilution threshold (mid)	L_2	Middle threshold for linear reserve segment	0.5
Invoice dilution threshold (high)	L_3	Threshold after which full reserve is required	0.75
Invoice reserve at L_1	k_1	Minimum reserve for small dilution levels	0.00009
Invoice reserve at L_2	k_2	Mid-level reserve before final ramp-up	0.5
Upper bound for billing distribution multiplier	B_1	Max multiplier for perfectly stable billing	1.1
Lower bound for billing distribution multiplier	B_2	Min multiplier for highly erratic billing	0.8
Upper bound scale factor (billing regularity)	k_3	Derived from Popoviciu's inequality	$\frac{1}{2}\sqrt{\frac{6}{5}}$
Critical penalty for disqualifying status	S_{penalty}	Overrides scores to enforce ineligibility	−10,000
Risk score thresholds	T_0, T_1, T_2, T_3, T_4	Tier thresholds for M_s mapping	100, 70, 30, 15, 0
Risk multipliers	M_1, M_2, M_3, M_4	Multipliers for risk score brackets	0.25, 0.5, 0.75, 1.0
Index set for M_s function	$\mathcal{J}$	Indexes active risk tiers in mapping	$\{1, 2, 3, 4, 5\}$
Weights for risk dimensions	$W_1, \ldots, W_6$	Importance weights for S_1 to S_6	[0,5]

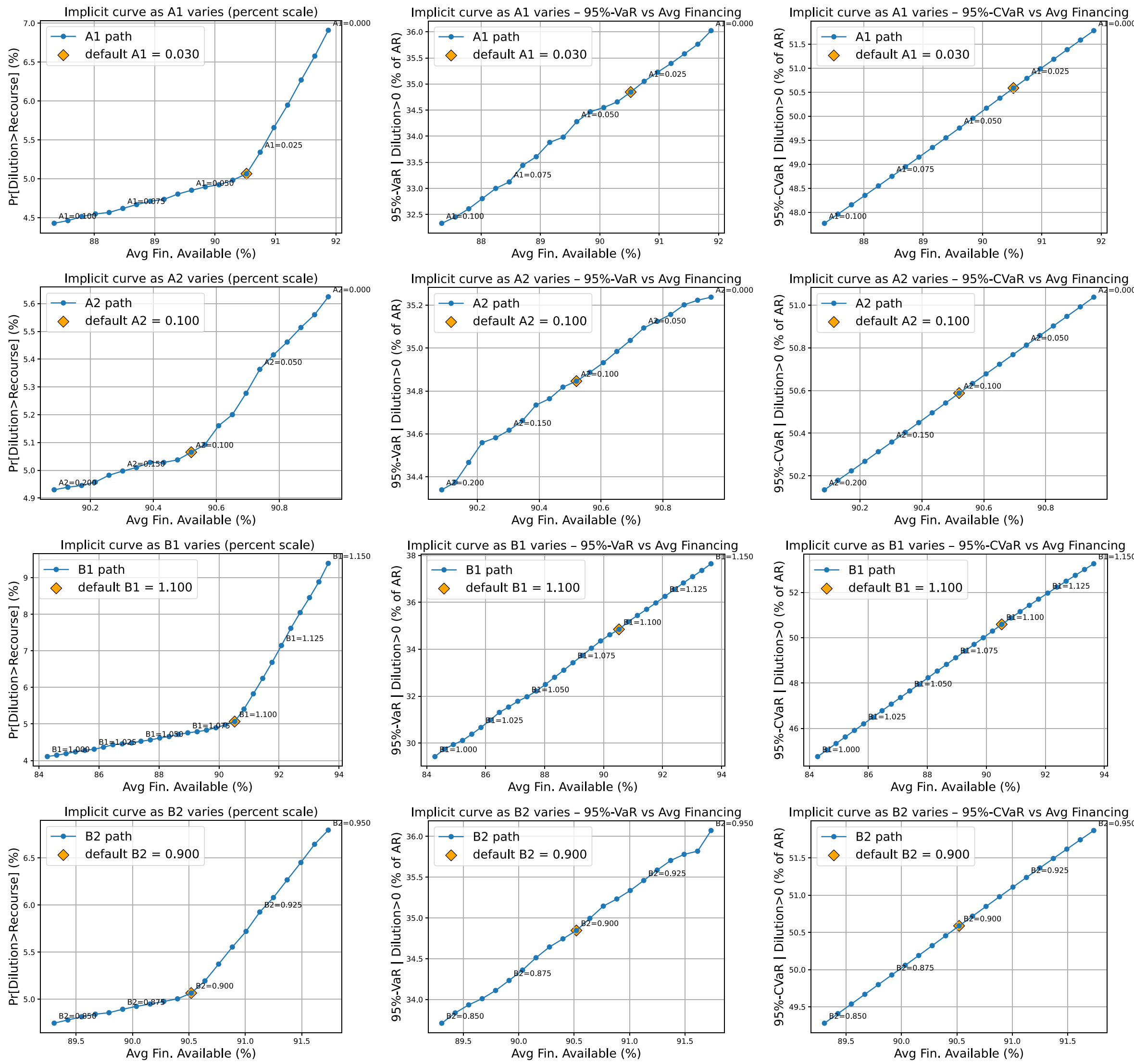

Fig. 5. Relationship between financing available and provider's risk as DCL parameter values change.
Note: Diamond corresponds to the default parameter value.

we demonstrate that DCL outperforms traditional invoice financing methods, providing more liquidity, reducing the risk of under-recovery, and significantly lowering the frequency of escalated collections.

The DCL algorithm achieves this by dynamically adjusting funding levels based on transaction histories, payment behavior, and real-time supplier risk assessments. We document the algorithm in full, clarify its implementation logic, and provide a structured parameterization that allows for replication or adaptation. Importantly, the algorithm not only works in theory—it has proven effective at scale in practice.

Our findings suggest that DCL can serve as a viable alternative to traditional SCF arrangements, especially in settings where irrevocable payment undertakings are impractical. By mitigating dilution risk through forward-looking risk analytics and structured recourse mechanisms, DCLs expand access to financing for a broader population of buyers and suppliers. We hope this study encourages further research and implementation efforts in post-undertaking SCF solutions.

This study opens several avenues for further work. From a modeling perspective, future research could explore more granular representations of risk propagation across invoices, buyers, and supplier networks. A key challenge is to improve the calibration of parameters, which are currently based on expert tuning, by utilizing machine learning or optimization techniques. Additionally, recent advances in AI and predictive analytics may contribute to more accurate forecasting of dilution risk and dynamic adjustment of recourse strategies. Moreover, researchers could study how DCL logic can be extended to multi-tier supply chains or used to design mechanisms that push the efficiency frontier further, enabling even greater liquidity with lower risk exposure.

Finally, for practitioners, DCL offers a scalable, data-driven method to extend financing even when buyer guarantees are unavailable. Finance providers can use the documented algorithm to mitigate dilution risk while serving a broader and more diverse supplier base. The approach requires access to transaction-level invoice and payment data, as well as a minimum level of integration with buyers' approval systems, but does not require a buyer-side commitment to irrevocable payment. Managers seeking to strengthen upstream supply chains or improve access to liquidity for underbanked suppliers can implement DCL as a flexible alternative to traditional SCF programs. The approach also enables fine-tuned risk control through parameter adjustments, making it adaptable to various industries and supplier segments.

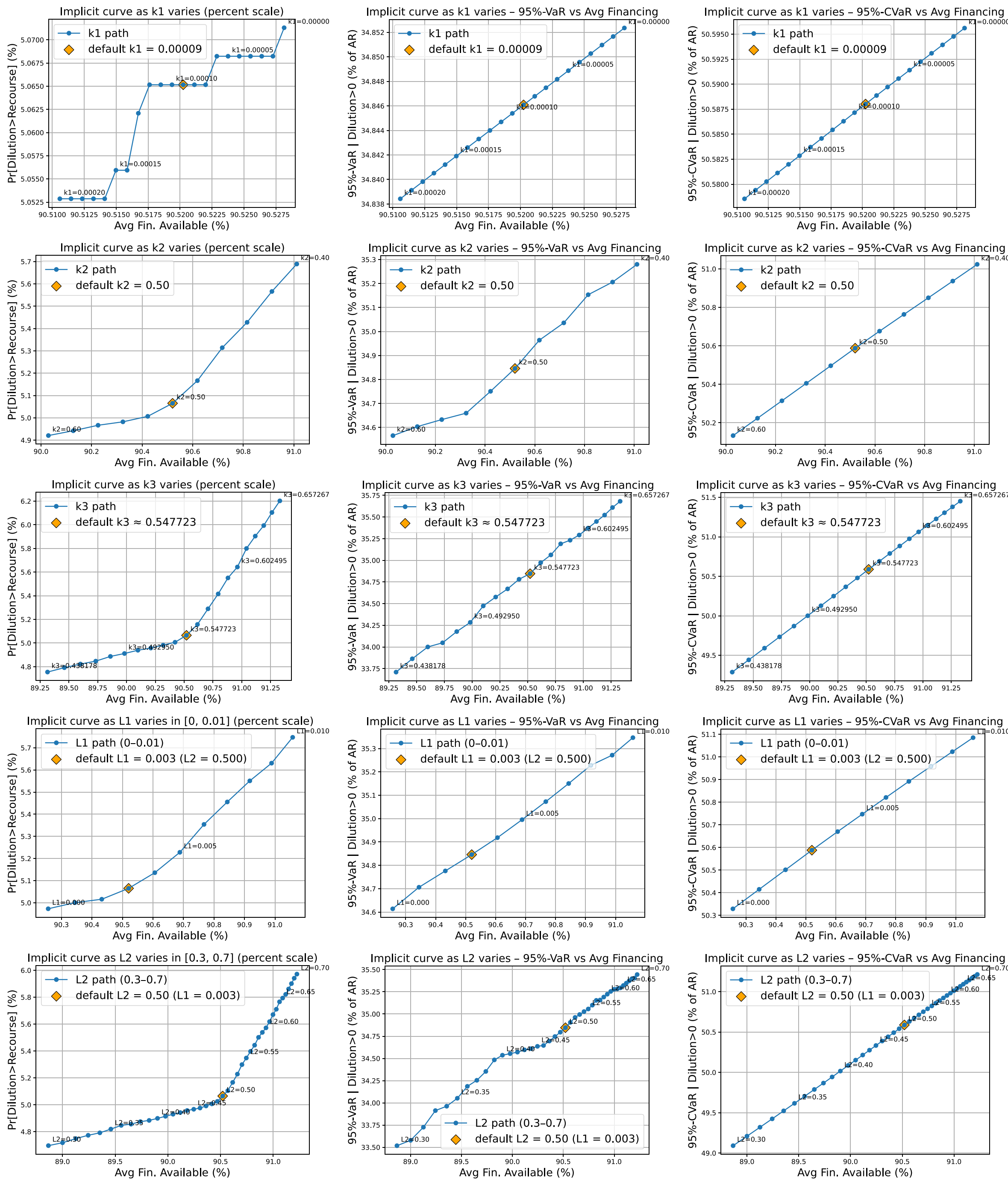

Fig. 6. Relationship between financing available and provider's risk as DCL parameter values change, continued.
Note: Diamond corresponds to the default parameter value.

CRediT authorship contribution statement

George Shapiro: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Volodymyr Babich:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **David Wuttke:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Grammarly and OpenAI for minor language improvements. After using these tools, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Data availability

The data that has been used is confidential.

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