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RESEARCH ARTICLE

The Nature of the Circular Firm: A Professional Paper in Economic Theory and Circular Economy

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Abstract

This paper advances a microeconomic theory of the circular firm that explains how and when circular practices become rational under real constraints. Departing from the timeless optimizer of linear models, I posit circular firms as survival-oriented organizations that accept transitional inefficiencies to secure long-run viability. The theory (i) reframes inputs as stratified by lineage and quality, distinguishing first-order materials from second-order infrastructures and institutions; (ii) relocates transaction costs to the centre of analysis, expanding firm boundaries to co-create reverse flows; and (iii) specifies a temporal adoption path: entry, hybrid, maturity. Under which positive profit, credible learning curves, and liquid secondary input markets align. Treating waste as property and price as the carrier of continuity, the model identifies minimalist policy fulcrums (differential disposal pricing, property rights in residuals, lean standards) that allow market signals to internalize durability, recovery, and reuse. I integrate insights from evolutionary economics, transaction-cost theory, durable-goods strategy, and closed-loop operations to derive testable implications for firm design, market organization, and public policy. The result is the emergence of a tractable decision logic that moves CE from promise to practice for firms either looking to transition or enter markets as circular producers.

Keywords Circular Economy · Sustainable Development · Microeconomics · Firm · Transaction Cost · Circular Design · Regenerative Practices · Closed-Loop Systems · Circularity

JEL Category D21 · D23 · P49 · A12

"The formulation of a problem is often more essential than its solution"

- Einstein, A., & Infeld, L. (1938, p.92)

1. Introduction

The call for a circular economy (CE) has gained remarkable traction in recent decades, propelled by escalating environmental stress, resource scarcity, and the intensifying urgency of energy transition. At the macro level, scholars have shown that circular practices are increasingly framed as responses to systemic constraints diminishing material stocks, volatile energy markets, and policy pressures for decarbonization (Ghazanfari, 2023). Yet macro-level urgency, however persuasive, does not by itself deliver a theory of how firms behave within such a system.

CE has thus been promoted not only as a sustainability paradigm but as a strategic business imperative. It is argued to be a driver of new competitive advantages, capable of reshaping markets and firm trajectories by transforming waste into resources and aligning with consumer values (Barros et al., 2021). This emphasis

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rightly foregrounds the role of firms, but the theoretical underpinnings at the microeconomic level remain underdeveloped. Without them, CE risks remaining a policy slogan rather than a coherent economic logic.

The interdisciplinary character of CE research is both its strength and its vulnerability. As noted, CE has rapidly emerged as a novel research field straddling engineering, policy, and sustainability science, yet lacking rigorous foundations in economic theory (Kirchherr et al., 2023). Indeed, definitional ambiguity is a hallmark: one study identified 114 competing definitions of CE, underscoring the absence of shared conceptual clarity (Kirchherr et al., 2017). This definitional inflation, while signalling intellectual energy, dilutes analytical precision and weakens the theoretical traction of CE at the level of firm decision-making.

Critics have warned that CE risks devolving into a hollow paradigm unless its conceptual rigor is tightened and its implementation grounded in real economic dynamics (Corvellec et al., 2022). Empirical studies reinforce this concern: CE in practice has shown only modest effects in reducing natural resource extraction, raising doubts about its transformative capacity if firm behaviour continues to be modelled through linear economy (LE) assumptions (Bianchi et al., 2023).

At the same time, the policy and sustainability discourse continues to elevate CE as a mechanism for combating climate change and reducing emissions (Yang et al., 2023). Yet as Velenturf and Purnell (2021) argue, there remains a profound disconnect between the rhetoric of circularity and the actual sustainability outcomes delivered, highlighting the need for models that link firm behaviour to systemic transformation. Concrete case studies echo this need: research on second-hand clothing markets shows that organizational form (for-profit vs. not-for-profit) significantly shapes material flows and equity outcomes, underscoring the importance of microeconomic structures and incentives in shaping circular outcomes (Persson & Hinton, 2023).

Ultimately, CE's normative rationale is ecological as well as economic. Scholars such as Morseletto (2022) have emphasized that a sustainable circular framework must go beyond efficiency rhetoric to reimagine the input-output assumptions embedded in modern economics. To realize this ambition, however, CE requires not only new policies or technologies, but new theoretical foundations, particularly at the microeconomic level, where firm decisions about costs, survival, and market positioning determine whether circularity becomes systemic logic or remains marginal practice.

What follows advances a microeconomic theory of the circular, it assumes familiarity with economic theory, circular economy (CE) theory, and finance and transformation practices within firms. The intended audience includes CE scholars and practitioners, economists, policy analysts, and corporate leaders in finance and transformation seeking to implement CE initiatives in established or emerging firms.

The paper grounded in the following contributions to the literature:

1. It reconstructs the core assumptions of microeconomic theory for circular production, replacing static optimization, homogeneous inputs, and frictionless exchange with temporal decision-making, stratified inputs, and transaction-cost-driven adaptation.
2. It specifies distinct boundary conditions for the circular firm, extending Coasean theory to reverse material flows and identifying integrator firms as structurally necessary actors where internal coordination is cost prohibitive.
3. It reframes firm rationality as survival-oriented rather than maximization-driven, formalizing circular investment viability through conditions of solvency, declining reintegration costs, and credible net present value under dynamic cost and savings structures.
4. It argues that price-based coordination, rather than comprehensive traceability regimes, is the primary mechanism through which circular markets scale and mature, with legal and policy institutions serving to enable price signals rather than replace them.

2. Literature review

2.1. Foundations in Economic Theory and Firm Behaviour

The classical firm, rendered as a frictionless calculator of marginal conditions, has long been treated as a machine for maximization. The circular economy (CE) makes this gap visible. If waste is to be reclassified from residual to resource, if inputs are to be re-specified as flows across time rather than one-time extractions, *then the firm's decision problem must be rebuilt from the ground up*: not as ceteris paribus optimization, but as *adaptive endurance*.

Alchian's (1950) evolutionary proposition is the proper point of departure. Firms do not need to maximize; they need to persist. Positive profit, not maximum profit, is the criterion for selection. Under the uncertainty of the real world, experimentation becomes rational; imitation and learning constitute endogenous forces; and expectations about future costs and markets legitimately shape present conduct (Alchian, 1950). The circular firm, in this sense, is not a moral outlier *but a recognizably economic actor*: it accepts short-run frictions (sorting, reverse logistics, redesign) to accumulate options for long-run viability.

This evolutionary realism stands in productive tension with the prevailing CE discourse. On one hand, CE has been promoted as a strategic business imperative, aligning internal values with reputational gains, customer loyalty, and prospective cost advantages (Barros et al., 2021). On the other, leading critics warn that CE can devolve into technocratic modelling or sloganized virtue if it is not anchored in the behaviour of actual firms facing real constraints (Kirchherr, 2023; Hartley & Kirchherr, 2023). The theoretical pivot, therefore, is not whether CE is desirable in the abstract, but whether we can specify a decision logic under which firms adopt circular practices while meeting the survival test that markets impose.

First, the normative foundations of CE must be made explicit. Ecological limits and intergenerational risk alter the background conditions of economic reasoning; the "given" of abundant inputs is no longer given (Morseletto, 2022). A sustainable circular framework requires rethinking the input–output language of production so that stocks, flows, and regeneration are not afterthoughts but primitives. Second, the empirical record must discipline theory. Even sympathetic evaluations find that CE's material impact on resource extraction has been, at best, modest to date, a function not only of policy design but of firm behaviour, market organization, and quality of inputs (e.g., contamination, heterogeneity) (Velenturf & Purnell, 2021; Ghisellini et al., 2016). If outcomes disappoint, the explanation is unlikely to be purely rhetorical failure; it is structural, rooted in incentives, costs, and information.

Within this frame, the firm's "values" matter, but not as free-floating ideals. Values are economically operative where they affect customer acquisition, employee motivation, capital access, and regulatory positioning. All channels that can sustain positive profit during transitional phases when costs are temporarily high (Barros et al., 2021). The literature on organizational form sharpens the point: different legal and governance arrangements (for-profit versus not-for-profit, mission-locked hybrids) systematically shape how decisions are made and how circular practices are prioritized, especially in markets like second-hand apparel where reuse, repair, and redistribution are core (Persson & Hinton, 2023). A micro theory that ignores ownership, purpose, and stakeholder commitments will misread CE adoption as mere "preference," when it is frequently an institutional capability.

From here, the conceptual ambiguities of CE become analytically useful rather than paralyzing. The definitional proliferation documented by syntheses and reviews (Ghisellini et al., 2016) signals a field still negotiating its own boundaries. Instead of treating this as a defect, we can treat it as an invitation to specify what matters for firm behaviour: (a) how inputs are sourced (primary vs. secondary), (b) how product architecture enables or blocks reuse (design for disassembly, modularity), and (c) how temporal cost profiles evolve as infrastructure and markets mature. The result is a shift from "CE as paradigm" to "*CE as decision environment*," where the core variables are costs (fixed, variable, coordination), quality tiers of secondary inputs, and credible expectations about their trajectories over time.

Crucially, this reframing aligns with critics who caution against model-centric CE narratives that paper over institutional frictions (Kirchherr, 2023; Hartley & Kirchherr, 2023**)**. Firms do not switch input regimes because a systems diagram says they should; they switch when three conditions cohere: (1) the short run remains solvent (*positive profit/temporary loss*), (2) the long run is plausibly superior (*net present value under realistic learning and scale effects*), and (3) organizational form and stakeholder arrangements can actually deliver on (1) and (2). *Where these conditions are absent, "circularity" becomes branding; where they are present, it becomes rational logic for a production structure.*[2]

[2] Practices commonly described as "circular" are not historically new. Industrial systems have often reabsorbed by-products when economic conditions made disposal costly or reuse valuable. A well-known example is gasoline, which initially emerged as a low-value by-product of kerosene refining and was often discarded before being internalized as a core product once technological change and market demand aligned (Yergin, 1991). What is distinctive in contemporary circular economy discourse is therefore not the existence of reuse itself, but the explicit alignment of such practices with sustainability/regeneration regimes, environmental objectives, and policy frameworks rather than their incidental emergence through market forces alone.

Finally, ecological and sustainability principles press a stricter question: not merely whether circular adoption is privately rational, but whether it is socially effective. As Velenturf and Purnell (2021) argue, there is a persistent disconnect between CE practice and sustainability outcomes; without aligning firm-level incentives to system-level goals, we risk well-intentioned substitutions that displace rather than reduce impacts. Morseletto (2022) reinforces the point: to be genuinely modern, economic frameworks must internalize environmental principles at their core. For micro theory, this implies that waste must be treated as property to drive input markets with its own grades, prices, and institutions; that coordination and information costs are first-order variables; and that survival-oriented firms will rationally co-produce the infrastructures (reverse logistics, quality standards, customer participation) required to make secondary inputs rival primary ones in price and reliability over time.

2.2. Circular Frameworks, Business Models, and Decision Environment

For more than a decade, CE has been heralded as a transformative model, yet what exactly it transforms, and how, remains unsettled. As Geissdoerfer et al. (2017) observe, CE has come to function as both paradigm and placeholder: a vision of sustainability that accumulates rhetorical force precisely because of its ambiguity. Reviews confirm this definitional proliferation, with CE framed variously as industrial strategy, ecological ethic, or systemic transition, often without a stable analytic grammar (Ghisellini et al., 2016).

This ambiguity is better treated as a productive opening. *To build a theory of the circular firm is not to stipulate a single master definition of CE, but to specify the conditions under which firms act as circular agents.* The literature on business model innovation is instructive here. Studies of transition pathways identify not just “start-ups” born circular, but incumbents navigating incremental transformations, spin-offs, and hybrid arrangements, all responding to different constellations of drivers and barriers (Geissdoerfer et al, 2023).

At the same time, the theoretical architecture of CE remains underdeveloped. Scholars have called for frameworks that move beyond catalogues of practice toward formal models capable of clarifying firm behaviour and system effects (Mignacca et al, 2025). Without such specification, CE risks becoming what Kirchherr (2023) calls a “buzzword.”

Empirical studies suggest that the most resilient circular firms are not those maximizing efficiency in the short term, but those embedding values and narratives that support long-run competitiveness. Internal commitments to sustainability can align with customer loyalty, reputational capital, and prospective cost advantages, producing a bridge across the high-cost transitional phase (Barros et al, 2021). Persson and Hinton’s (2023) work on second-hand clothing markets underscores the point: organizational form and legal architecture directly condition how circular strategies are enacted, whether through not-for-profit systems or mission-locked hybrids.

Macro-level treatments of CE as climate strategy (Yang et al., 2023) reinforce the stakes but also highlight the limitations of top-down visions. For individual firms, transition unfolds within hybrid regimes, sometimes linear, sometimes circular, where sunk assets, path dependencies, and uneven infrastructures constrain choice (Morseletto, 2020). That transitional hybridity is not a flaw; it is the real terrain on which firms test, learn, and recalibrate. Yet the systemic critiques remain potent: despite its promise, CE practice often fails to deliver genuine sustainability outcomes (Velenturf & Purnell, 2021). This mismatch between aspiration and outcome is not a failure of will but a failure of theory.

What remains under-specified across this literature is the decision logic by which firms evaluate circular transition under real constraints *ex ante*. Business model frameworks describe circular configurations *ex post*, while empirical studies document experimentation and hybridization, yet neither *consistently* specifies the conditions under which circular practices become economically rational for firms facing heterogeneous capital, immature markets, and high coordination costs.

As a result, firm behaviour is interpreted retrospectively rather than through a forward-looking account of feasibility, timing, and survivability. This limitation is most evident during transitional phases, when firms operate simultaneously within linear and circular regimes, absorbing short-term inefficiencies under uncertain long-run payoffs. Without an explicit account of the *decision environment in which such choices are made*, CE risks remaining descriptive rather than developing into a microeconomic theory capable of explaining when and why circularity emerges, stalls, or persists.

2.3. Operational Dimensions and Input Market Logic

Conceptual and evolutionary arguments only gain traction when tethered to the operational realities of production. The costs of collection, sorting, and remanufacture are not incidental frictions but defining variables in the firm's decision environment. Reverse logistics, networks for retrieving, grading, and reintegrating secondary materials have been consistently identified as the backbone of circular systems (Mallick et al, 2023). Additionally, they are also coordination-intensive, and deeply path dependent, requiring firms to build capabilities far afield from traditional supply management.

Measurement frameworks expose this same complexity. At the firm level, "circularity" is not a binary it is or it isn't, but a gradient of maturity, with indicators ranging from material intensity and design-for-disassembly to customer participation in take-back schemes (Stucki et al, 2023). These temporal markers map directly onto cost trajectories: fixed investments in redesign and logistics dominate the early phase, while variable costs and efficiency gains shape later competitiveness and gains.

Empirical analysis bears out this survival logic. A meta-analysis of CE adoption finds positive associations between circular practices and firm performance, but with significant variance by sector and strategy (Yin et al, 2023). This variance is not noise; it reflects the heterogeneity of input quality, market structure, and stakeholder coordination. As Fobbe (2023) points out in manufacturing, for instance, successful transitions hinge on embedding circularity within stakeholder networks, suppliers, customers, and regulators, rather than treating it as an internal cost–benefit calculation.

Technology and design add further layers. The principles of reduce, reuse, recycle, recover, redesign, and remanufacture (the "6Rs") articulate the technical repertoire available to firms, but they are not cost-neutral (Jawahir & Bradley, 2016). Each demands investments in new machinery, process redesign, and workforce training. *Fixed costs loom large, and economies of scale only materialize once secondary input streams achieve stability and reliability.*

Institutional arrangements shape outcomes just as much as technology. In markets like second-hand clothing, legal frameworks governing resale, hygiene, and consumer rights determine whether reuse becomes mainstream or marginal (Persson & Hinton, 2023). Without such institutional scaffolding, firms may experiment with circular practices but abandon them when coordination failures and cost overruns threaten solvency.

CE does not fail because firms are irrational or consumers inattentive, but because the operational infrastructures and market institutions remain underdeveloped (Velenturf & Purnell, 2021). Technocratic modelling that assumes away these challenges risks reproducing the very failures it seeks to solve (Hartley & Kirchherr, 2023). A viable micro theory must instead treat *waste* as an input market to Capital. Explicitly the *production structure* with its own price dynamics, quality tiers, and transaction costs.

2.4. Capital and The Production Structure

The circular economy literature has devoted increasing attention to capital as the physical and technological substrate through which material flows are organized. Within industrial ecology and circular transition research, capital is most often understood as an installed base of long-lived production assets whose slow turnover and sunk costs condition the pace and direction of change.

This framing has been particularly effective in identifying structural constraints in sectors such as metals, construction, plastics, and other energy-intensive industries, where infrastructure lock-in and path dependence limit the feasibility of rapid circular transformation (Pauliuk & Müller, 2014; Geissdoerfer et al., 2017; Cullen, 2017). By emphasizing asset longevity and material stocks, this literature explains why circular transitions tend to unfold incrementally rather than through immediate substitution of linear practices.

Related strands of CE scholarship deepen this account by examining capital rigidity, technological compatibility, and process feasibility at the level of production systems. Research on recycling, remanufacturing, and industrial symbiosis consistently shows that existing production structures are optimized for primary inputs, such that the integration of secondary materials requires additional preprocessing, buffering, or parallel infrastructures (Ghisellini et al., 2016; Kirchherr et al., 2017; Bocken et al., 2016).

These studies document coordination challenges, investment delays, and the persistence of hybrid linear–circular arrangements, yet capital is typically treated in aggregate or sectoral terms. Consequently, the internal structure of production the interdependencies among specific capital goods and their coordination across stages of production remains largely implicit. What remains underexplored is the extent to which circular transition reflects not only shifts in material flows, but a deeper process of capital restructuring unfolding over time and under uncertainty.

An alternative perspective on capital, developed outside the circular economy literature offers a sharper lens through which to interpret and diagnose these constraints. Hayek's (1941) theory of capital conceptualizes production as a time-structured sequence of heterogeneous and complementary goods, where coordination across stages is essential for economic coherence. Lachmann (1956) further emphasized that capital is not only heterogeneous but plan-specific: assets derive their value from how they are integrated within particular production plans under uncertainty.

These insights are directly relevant to circular production. Circular transitions do not involve substituting one material for another in isolation; they require reconfiguring interdependent capital combinations across time, often under conditions of uncertainty regarding recovery rates, material quality, and institutional support. From this perspective, many failures of circular initiatives reflect not a lack of commitment or technology, but coordination breakdowns within capital structures that were designed for linear throughput rather than material persistence (Faber et al., 1996; Velenturf & Purnell, 2021).

2.5. Waste in the Linear and Circular Economy

Economic theory has historically treated waste as something that lies outside the productive core of the economy. From classical political economy onward, waste appears not as an analytic condition of production, but as a residual, an inefficiency to be minimized rather than a constraint to be organized. In the work of Smith and Ricardo, waste is understood as spoilage, misallocation, or poor technique, reducing surplus but leaving the structure of production itself unchanged (Smith, 1776; Ricardo, 1817).

This treatment persists in Marx's analysis of capital. Although Marx places greater emphasis on circulation, turnover, and depreciation, waste remains a source of loss rather than a determinant of productive structure. Losses arising from unsold commodities, wear, or idle capital reduce realized surplus value, but they do not alter the underlying configuration of factors through which production is organized (Marx, 1885/1978).

Twentieth-century economic theory shifts attention again, this time toward uncertainty, expectations, and investment behaviour. In the work of Knight and Keynes, waste appears indirectly, as an outcome of error, misjudgement, or failed expectations under uncertainty, rather than as a persistent material constraint shaping future production possibilities (Knight, 1921; Keynes, 1936). More recent advances in contract and institutional economics relax assumptions of frictionless exchange, emphasizing residual control rights, transaction costs, and institutional persistence (Hart, 1995; North, 1990). Yet even here, waste remains analytically peripheral, treated as a by-product to be disposed of or regulated rather than as a factor shaping production structures themselves.

Across these traditions, a common assumption remains largely unexamined: *that disposal is inexpensive and that transactional closure coincides with material disappearance*. It is this assumption, rather than any explicit theoretical commitment that explains the persistent marginalization of waste within economic analysis, and it is precisely this assumption that circular production calls into question.

Under circular conditions, such an assumption no longer holds. Discarded outputs persist materially beyond the point of exchange and must me managed due to limits of absorption back into the natural world, but they also give rise to new and contingent value streams whose realization depends on coordination, recovery, and reintegration (Ayres and Kneese, 1969; Daly, 1991).

Waste therefore conditions future production in two distinct ways: *as a persistent material constraint that must be managed with dedicated scarce resources, and as a potential scarce source of value whose accessibility reshapes firm behaviour and capital structure*.

Treating waste as an analytic category, around persistence and potential value, allows for the extension of the traditional economic factor framework to account for both persistence and the emergence of secondary value streams where disposal no longer terminates economic relevance.

In this sense, waste becomes the *fourth factor of production* but does not revise established value theory; it rather extends it providing an analytic lens for understanding how material persistence and contingent value jointly reorganize production decisions and firm organization in a circular economy. This assumption sets the stage for us to reconsider the economic literature previously reserved for land labour and capital, explicitly considering through new eyes the impact of waste on the firm.[3]

3. The Nature of the Circular Firm

3.1. Recasting the Assumptions of Microeconomic Theory

In the neoclassical canon, base assumptions are devices of simplification: *ceteris paribus* to isolate causality, frictionless markets to illustrate supply and demand fluctuations, rational maximisers to justify equilibrium. The circular firm is not a timeless optimizer moving along smooth curves; it is a survival-oriented organism embedded in ecological constraint, path dependence, and institutional friction.

3.1.1. From Ceteris Paribus to Temporal Trajectories Circular transition is inherently temporal. Circular firms traverse a more complex sequence than the classical model: (1) entry, where fixed costs and coordination burdens dominate; (2) hybrid, where firms straddle linear and circular regimes; and (3) maturity, where scale effects and stabilized infrastructures lower circularity costs. Solvency is phased, not binary: firms endure thin margins or transitional losses if they can plausibly expect future competitiveness.

3.1.2. From Price-Taking to Market Co-Creation In Coase's (1937) formulation, the firm exists to internalize transactions when market exchange is costly. Reverse logistics, repair, remanufacture these cannot be treated solely as exogenous "markets" waiting to be tapped. They must be constituted by firm and policy together: through standards, collection networks, warranties, and certification. The circular firm is not a price-taker in secondary input markets; it is their co-creator.

3.1.3. From Maximization to Survival-Oriented Adaptation Orthodox rationality assumes firms maximize profit at the margin. Alchian (1950) argued otherwise: firms need not maximize; they need only persist. Firms accept short-run inefficiencies (sorting costs, modular redesign) to remain solvent while buying an option on long-run viability. *The assumption is survival is rational under uncertainty*.

3.1.4. From Frictionless Exchange to Transaction Costs as Structure In neoclassical theory, transaction costs are erased. In CE, they are everything. Sorting heterogeneous waste, negotiating take-back contracts, verifying secondary material quality, these are not distortions, they *are the economy*.

3.1.5. From Homogeneous Goods to Stratified Inputs Linear models assume goods are identical. Circular production begins with heterogeneity. Virgin and secondary materials differ in grade, reliability, and cost. Degradation of material quality is not an accident but a law (Georgescu-Roegen, 1971). First-order inputs, direct materials and energy are stratified by source and quality; second-order inputs, infrastructure, logistics,

[3] Treating waste as a factor of production is not a radical gesture in economic theory. It is simply a logical next step in response to its analytic omission rooted in the historical conditions of inexpensive disposal, limited material persistence, societal values, and technology constraints for re-integration. Under contemporary conditions, discarded materials persist much longer, absorb more scarce resources to manage (micro and macro), and increasingly generate contingent value streams thanks to technological advancement; recognizing waste as a factor of production both reflects this reality and allows the analytical tools applied to land, labour, and capital to be systematically extended to the management and integration of waste.

and institutions determine whether recoverable inputs can ever compete with virgin ones. *Thus, the assumption is quality and cost layered capital inputs and consumer inputs.*

3.1.6. From Perfect Information to Institutional Learning In circular markets, ignorance is endemic: secondary input prices are volatile, consumer demand is emergent, regulatory regimes are uncertain. Institutions, certification standards, producer responsibility laws, consumer labelling, scaffold the knowledge that firms and buyers require. *The assumption is adaptation is the causa prima of efficiency, not perfect knowledge.*

Table 1. Classic Versus Circular Assumptions

Classic Assumptions	Circular Assumptions
Static Equilibrium	Time Trajectories (Short-Term / Mid / Long Term)
Price Taking Firm	Market Forming Firm (Hybrid Taker / Maker)
Profit Maximizing	Positive Profit (Iterative Survival and Adaptation)
Frictionless Exchange	Cost Optimizing Exchange (Cost of exchange starts high and lowers through time)
Homogeneous Goods	Stratified Inputs
Perfect Information	Imperfect Information with High Discovery Costs

Taken together, the Circular Assumptions in **Table 1** replace the classic assumptions practically and expand their core logic to be inclusive of firms making a real shift toward circularity.

3.2. Survival as Maximization

In the circular economy, inputs are stratified by quality, markets are emergent rather than given, and costs shift as infrastructures mature. What remains real is survival.

Alchian's (1950) evolutionary proposition clarifies the shift: positive profit, not maximum profit, is the test of persistence. In linear theory, "suboptimal" choices are errors; in circular practice, they are strategies. A firm that invests in costly modular designs today, knowing they depress current margins, may ensure its survival tomorrow when repair, remanufacture, or resale become viable. In linear theory, this looks like inefficiency. In circular theory, it is rational endurance.

Georgescu-Roegen (1971) demonstrated that material quality always degrades; secondary inputs carry contamination, loss, and variability. Linear theory assumes away this dissipation, treating inputs as largely substitutable or elastic. Circular theory must assume the opposite: that every recovery incurs a discount in quality, and that survival requires experimentation, redundancy, and learning.

In the linear economy, waste is an externality: dumped downstream, priced at zero, someone else's problem. In the circular economy, waste is a liability and a potential resource simultaneously. Following Coase (1960), if externalities are internalized or influenced through liability, bargaining, or regulation, then survival requires accounting not just for labour and capital but for the infrastructures of recovery and reuse. *What was invisible in linear theory becomes central in circular theory*.

Even the role of firm values is inverted. In the linear economy, values are rhetorical at best, irrelevant to the marginal calculus, assumed away as ceteris paribus. In the circular economy, values matter precisely because they affect solvency: customers stay loyal to firms that design for repair; investors allocate capital to firms signalling credible sustainability; regulators grant license and goodwill where firms demonstrate alignment with ecological limits (Barros et al 2021; Persson & Hinton, 2023). In short, values cease to be a zero-sum-game and becomes a non-zero-sum-game contributing to survival. In the linear world maximization is elegant on paper but brittle in practice, its replacement survival is untidy in theory but durable in reality.

3.3. The Input–Output Grammar Rewritten

Every economy is a structure of transformation: inputs become outputs, labour becomes production, and what remains is cast off as waste. Production begins when resources arrive at the gate and ends when products leave it. Beyond that boundary lies silence as far as the firm is concerned.

Circular production breaks that silence. Inputs must be distinguished not by their price alone but by their lineage, entropy, and institutional scaffolding. A firm that draws on recycled aluminium does not purchase the same goods as one that draws on bauxite, even if the atoms are identical. The first purchase includes an inheritance of sorting, cleaning, and certification; the second assumes a geological subsidy.

To formalize this, the circular firm recognizes two distinct classes of input. **First-order inputs** are the virgin materials and energies of production: steel, water, labour, heat. **Second-order inputs** are the infrastructures, institutions, and knowledge systems that render the first usable: recoverable materials, reverse logistics, standards of purity, design-for-disassembly protocols, and the social contracts that govern participation. In linear theory, second-order inputs are invisible, dissolved into the background of "market conditions." *In circular theory, they are constitutive. Without them, circular inputs remain debris, not resources.*

Ayres and Kneese (1969) offered the technical foundation for this reclassification when they framed production as a *materials-balance system*: every inflow must equal the sum of outflows, whether as product, emission, or waste. Circularity does not escape this accounting; it extends it. To reintroduce waste as a resource is to add new and enhance established transformation functions, not to diminish them. Georgescu-Roegen (1971) reminded us that entropy is the ultimate accountant: every act of reuse carries a discount in quality, a loss in potential. The circular firm survives not by denying this loss, but by organizing a roundabout production structure around it, developing second-order capabilities that acknowledge heterogeneity and degradation and reintegrate it across time.[4]

3.3.1. Circular Firm Transition Through Time

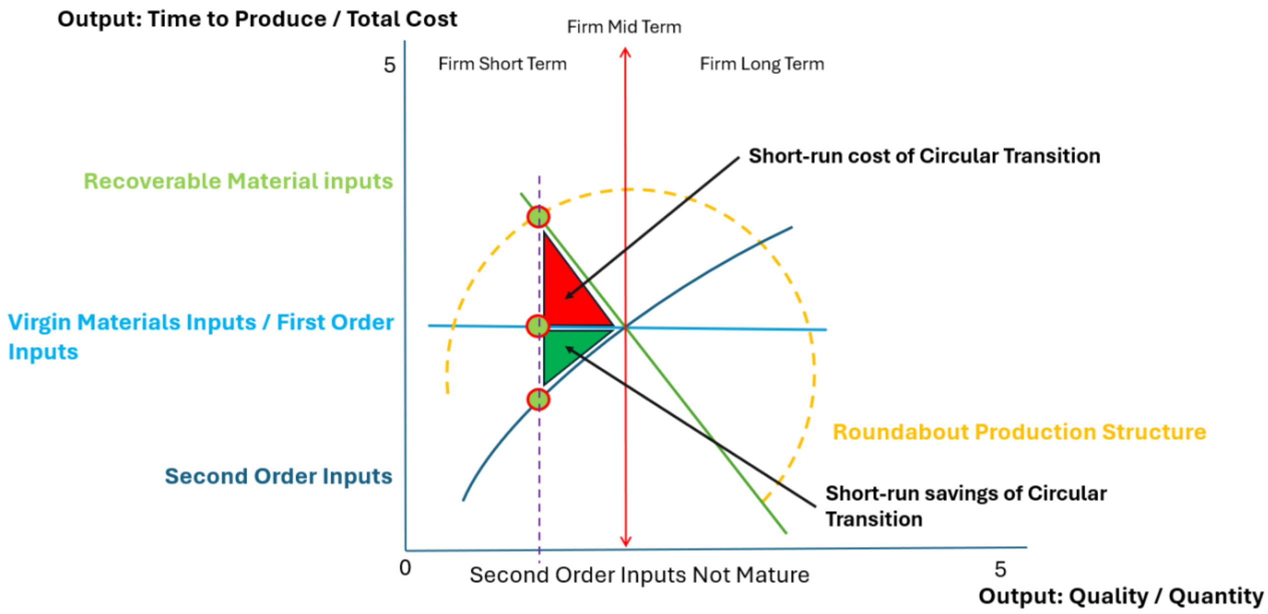

Figure 1A. Circularity Costs in Firm Short-Term

[4] Roundabout production structures are significant because they extend the temporal length of production to reorganize inputs into more productive combinations, accepting short-run cost and delay as the necessary condition for higher and more resilient output once complementary capital, knowledge, and coordination have matured. (Mises, 1949)

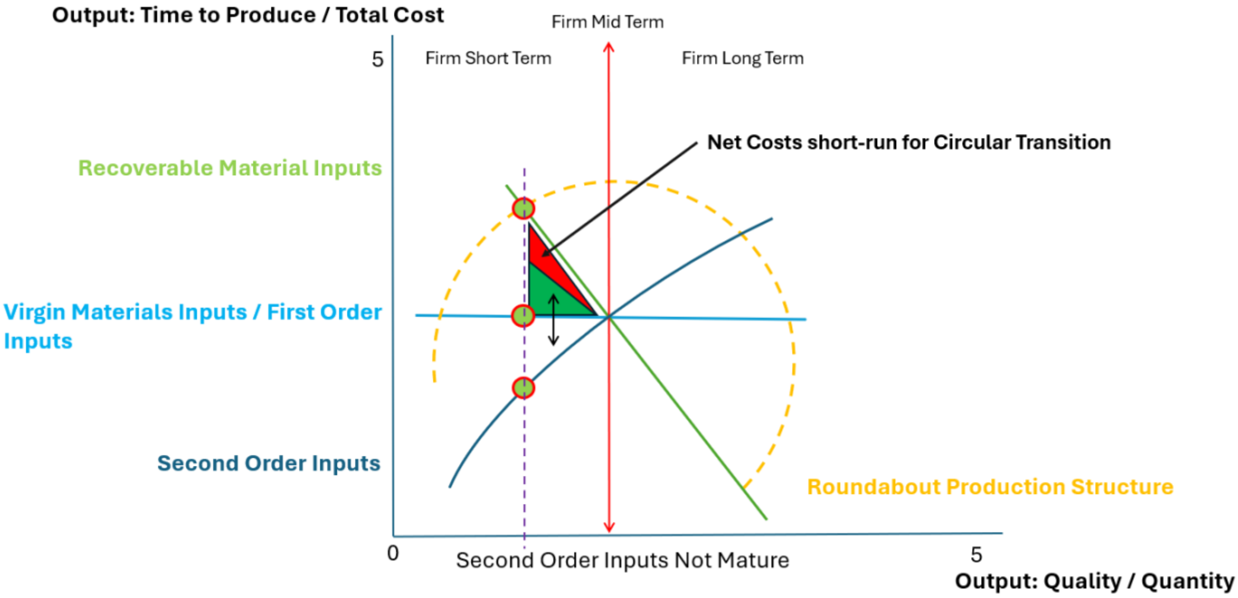

Figure 1B. Net Circularity Costs in Firm Short-Term

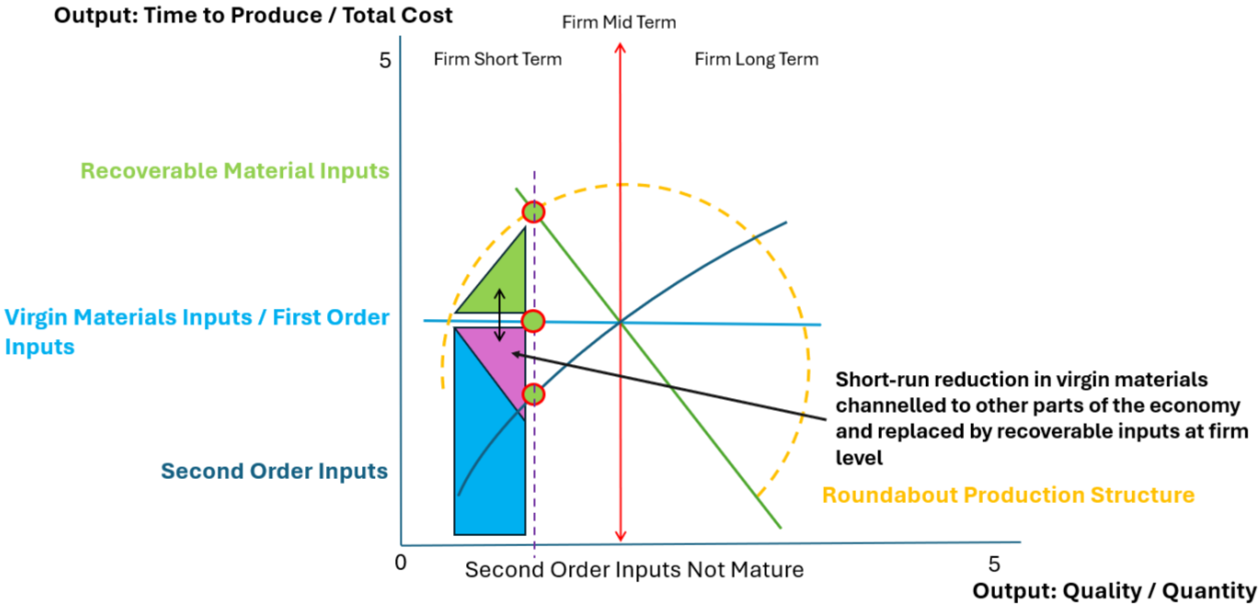

Figure 1C. Virgin Material Substitutes in Firm Short-Term

In the short-term shown in **Figures 1A, 1B, 1C**, the introduction of circular inputs imposes additional coordination, quality, and timing costs because second-order inputs are not yet mature. Recoverable materials substitute imperfectly for virgin inputs, requiring roundabout production structures that lengthen production time and raise total cost. Although some savings arise from reduced virgin material use, these are outweighed by transition costs associated with uncertainty, fragmented recovery systems, and incomplete learning. As a result, circular production appears cost-inefficient in the short run, not due to intrinsic inefficiency, but because the supporting production structure change has not yet stabilized.

- ***Illustrative Integral - Short Term Challenge:***

$$[S_1(t)]_+ - [S_0(t)]_+ \leq \mathbf{0}$$ [5]

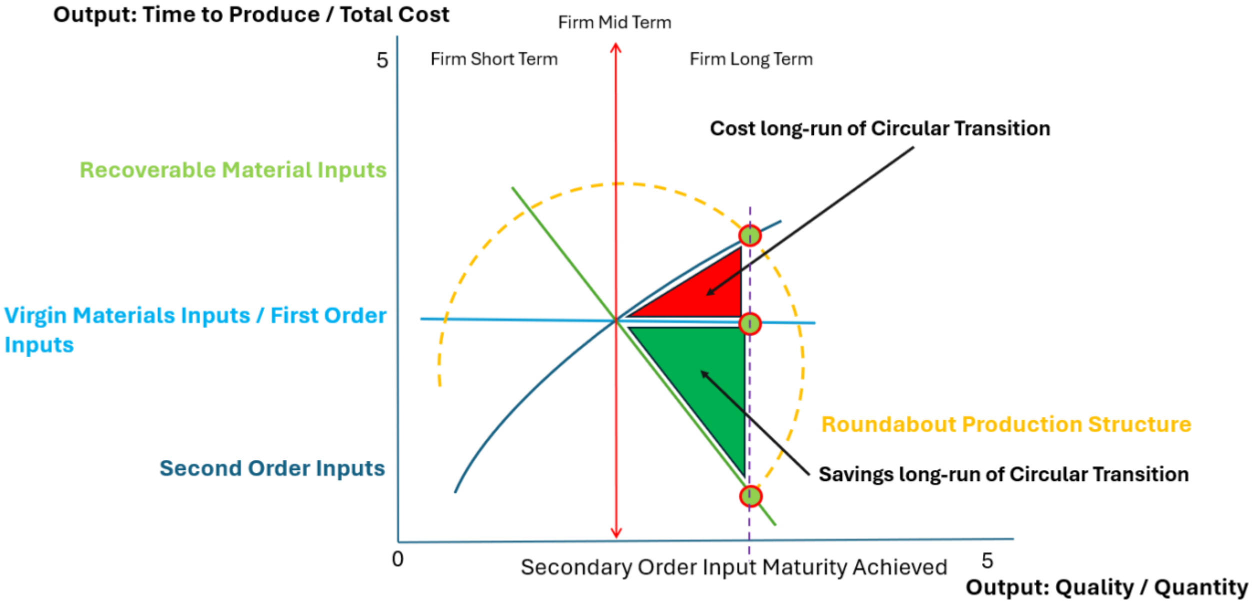

Figure 2A. Circularity Savings in Firm Long-Term

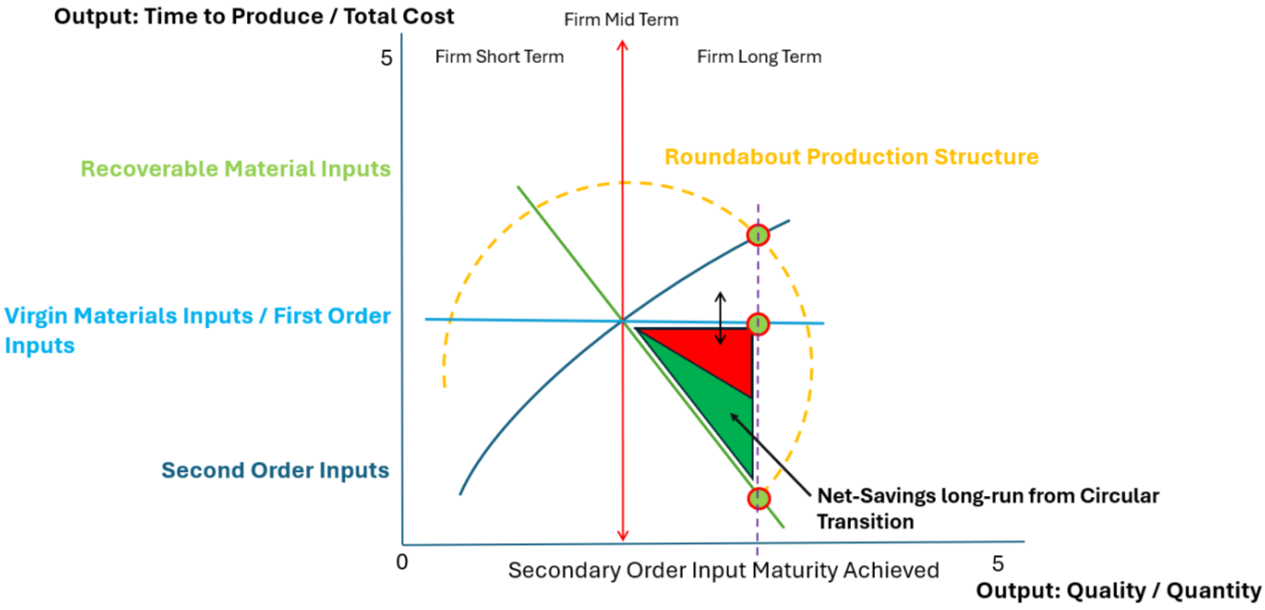

Figure 2B. Net Circularity Savings in Firm Long-Term

[5] See Boundary Viability Principle on Page 14

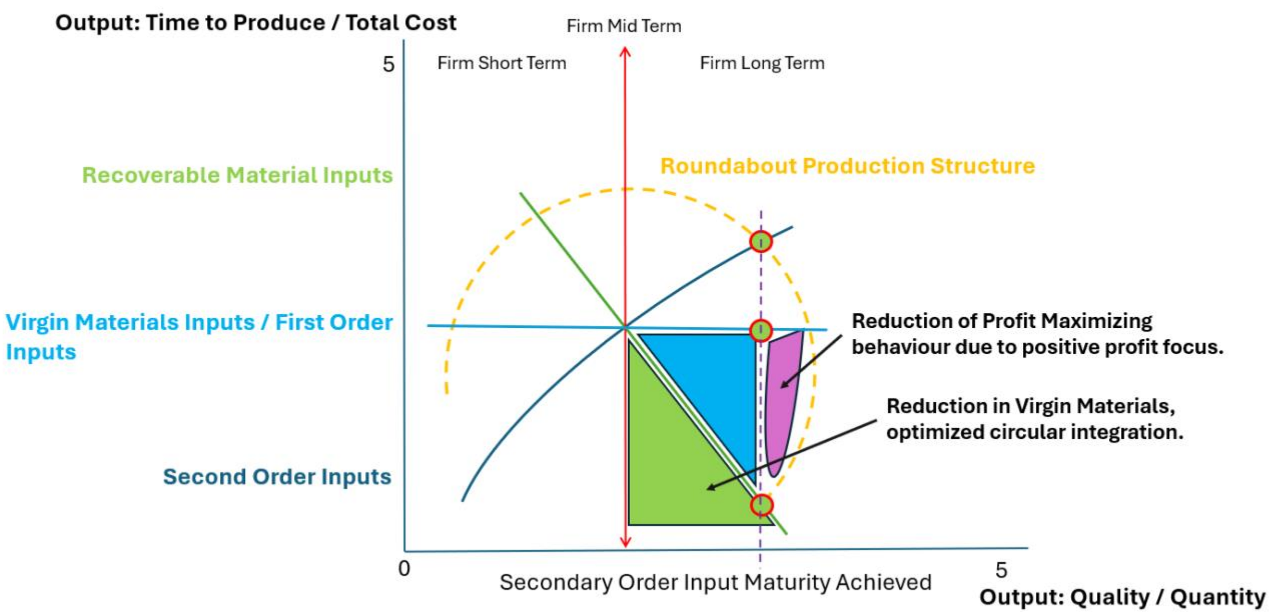

Figure 2C. Virgin Material Substitutes in Firm Long-Term

In the long term shown in **Figures 2A, 2B, 2C**, once second-order inputs achieve sufficient maturity and reliability, circular production becomes structurally efficient. Recoverable materials function as effective substitutes for virgin inputs, reducing first-order input dependence and stabilizing production flows. The same roundabout production structures that imposed short-term costs now generate sustained savings through improved input security, lower marginal costs, and higher output quality. Under these conditions, circular integration supports positive and resilient profit outcomes.

- ***Illustrative Integral - Long Term Opportunity:***

$$\int_0^T e^{(-rt)} \left([S_1(t)]_+ - [S_0(t)]_+ \right) dt > 0$$ [6]

In practical terms, this means the boundary of the firm shifts. Coase (1937) described the firm's perimeter as the zone where transaction costs make internal coordination more efficient than market exchange. Circularity redraws that perimeter around *reverse flows*: collection, sorting, remanufacture, repair. These activities, once externalized, now fall within the firm's or the industries rational domain because they stabilize input quality and reduce long-run uncertainty.

This, then, is the new grammar:

$Input_1$ (materials, energy) + $Input_2$ (infrastructure, coordination) → Output (product, service) + Residual (potential input of next cycle)

It is not a closed loop, entropy forbids that, but a tightening spiral, where each rotation depends on the refinement of second-order inputs. Stahel (2016) and Mont (2002) capture this in their models of product–service systems: design for durability and reuse lengthens the temporal arc of $Input_1$, while feedback systems and take-back programs strengthen $Input_2$. Tukker (2004) extended this further, showing that firms can reconfigure their revenue logic, selling access over ownership, to internalize the costs and benefits of long product life.

Where the linear model reads "produce, consume, discard," the circular model reads "design, coordinate, recover." The former presumes that markets handle the tail of the process; the latter understands that markets themselves must first be formed to circulate degraded matter as valued input and incentivize firm entry. The circular firm, in rewriting this grammar, does not abolish linear economy, *it completes it*.

[6] See Boundary Viability Principle on page 14.

3.4. Transaction Costs and the Boundary of the Circular Firm

The boundary of the firm is never natural; it is an act of deliberate design.

For the circular firm costs do not end at sale, and its liabilities do not vanish at disposal. Once materials are conceived as potential inputs rather than terminal residues, the boundary of the firm must expand to include their return. The transaction cost frontier moves backward through the supply chain and forward through time. It now includes not only the procurement of virgin resources but the orchestration of their eventual re-entry.

In this light, reverse logistics is not a service, it is a core requirement. Savaskan, Bhattacharya, and Van Wassenhove (2004) formalized this insight operationally: when firms control the take-back mechanism, collection rates rise and secondary material quality improves. Whether to internalize or outsource these functions becomes the new make-or-buy problem of the circular age.

Each expansion of internal responsibility carries its own coordination burden. Reverse flows are geographically dispersed, temporally staggered, and informationally noisy. Ferrer and Swaminathan (2006) showed how firms managing both new and remanufactured lines confront joint-pricing dilemmas: too much cannibalization, and the secondary market erodes the primary; too little integration, and the loop collapses. The linear firm avoids this tension by disposal. The circular firm must live within it.

Here, transaction cost theory intersects with institutional evolution. As Guide and Van Wassenhove (2009) documented, closed-loop systems mature through phases, informal recovery, structured collection, formal reverse supply chains, each requiring new second-order inputs: standards, certifications, and trust. The firm becomes less a single actor and more an orchestrator of ecosystems. The transaction, once the atom of market exchange, now stretches across a fluctuating edge of partners whose coordination of what can be re-absorbed into production is the very condition of value.[7]

Circularity also generates *new species of firms*, entities evolved precisely to manage the flow between waste and production. These are the intermediaries of reintegration: waste exchanges, reprocessing consortia, digital material platforms, and logistics networks whose product is not a thing but a function, continuity. They emerge where transaction costs are too high for any single producer to bear, but too systemic to leave unattended.

Savaskan, Bhattacharya, and Van Wassenhove (2004) hinted at this in their models of reverse channels. When producers cannot economically retrieve dispersed products, specialized collectors arise, performing the coordination task as a market service. Guide and Van Wassenhove (2009) later traced the institutional maturation of such systems: from ad hoc recovery toward formalized closed-loop chains, often populated by firms that never produced an original good. These intermediaries exist to make circular firms promises operable when they themselves cannot.

When the marginal cost of internal coordination exceeds the price of contracting with a specialist, a new firm appears. This is not market failure; it is market correction through institutional differentiation. In the linear world, these boundary firms were invisible because waste was unowned. *In the circular world, they are inevitable because waste must become property.*

Atasu and Subramanian (2012) and the OECD (2024) capture the policy counterpart: extended producer responsibility (EPR) regimes often induce the creation of producer responsibility organizations: collective entities that manage take-back, sorting, and certification. They are collective coordinators born from the necessity of lowering the informational and logistical friction of circular reintegration. Their emergence, and the emergence of other entities such as pre-competitive coalitions, is not an anomaly but a system adaptation to the maturity vacuum within the circular economy.

Thus, the circular economy produces not merely new behaviours by established firms but new organizations, coalitions, and their forms various forms driving growth. The producer-firm evolves by extension; the integrator-firm evolves by invention. One expands to internalize; the other emerges to specialize. Both are responses to the same structural pressure, the rising cost of coordination in a world where waste stays on the books, turning disposal into coordination and transforming the right to discard into the cost of continuation.

[7] Here moving from profit maximization to a positive profit model has an elegant interplay with Coasean boundary conditions where profit maximizing behaviour is not really lost but rather substituted for boundary maximizing behaviour to realize CE integrations.

3.5. Durability and the Time Structure of Circular Production

In the circular economy, nothing vanishes. The firm inherits what it creates. Materials decay, products wear, and obligations accumulate.

The economics of durable goods offers both a warning and a blueprint. Bulow (1982) and Waldman (2003) demonstrated how, in the linear market, durability threatens the producer's future sales. A firm that builds to last erodes its own demand. The circular firm reverses this equation. Durability becomes a source of strategic advantage, not a liability. By designing for repair, remanufacture, or shared use (Stahel, 2016; Mont, 2002; Tukker, 2004), the firm transforms longevity into the product, instead of selling a final consumer or capital good the firm *sells a service of renewal that endures.*

But endurance has costs of its own. The firm must track products in use, manage returns, plan refurbishment, and price access across time. Debo, Toktay, and Van Wassenhove (2005) described this as a dual-market logic: new and recovered goods coexist, their balance depending on return rates, technology, and consumer trust. For the circular firm, this coexistence is not a temporary phase, it is a long-run equilibration.

The durable product extends the firm's reach into the future, linking present profit to future material availability. Stahel's (2016) "performance economy" captures this precisely: *value lies in the function delivered over time, not in the transfer of ownership at once.* The firm's task is no longer to accelerate turnover but to sustain coherence: to design products, relationships, and infrastructures that endure longer than the costs of keeping them alive.

To determine if a linear firm can expand its boundary we must acknowledge the ***Boundary Viability Principle***: Boundary expansion in circular systems is economically justified only when the internalization of reverse flows reduces long-run coordination and material costs sufficiently, and early enough, to generate positive net present value; where this condition is not met, coordination will migrate outward through the emergence of specialized intermediary firms rather than inward through producer expansion *where legal frameworks and incentives encourage such activity*.

The integral below is illustrative of the continuous, time-weighted comparison of positive net savings under internalization versus external coordination once circular operations become viable.

$$\int_0^T \boldsymbol{e^{\wedge}(-rt)\,([S_1(t)]_+ - [S_0(t)]_+)\,dt > 0}$$

The firm creates circular value only when boundary expansion generates greater cost-positive performance than alternative arrangements, and the total economic benefit is the discounted accumulation of that difference over time.

$S_1(t)$ - net savings at time t under boundary expansion, reflecting internalized coordination of recovery, reintegration, and stewardship.

$S_0(t)$ - net savings at time t under the externalized or market-based arrangement.

e^{-rt} - the discount factor, capturing the declining economic relevance of savings realized further into the future.

dt - an infinitesimal unit of time, indicating that differences in value accrue continuously as cost structures evolve rather than at discrete decision points.

Circularity is not achieved by expanding firm responsibility indiscriminately, but by expanding it selectively, only where internal coordination produces sustained, discounted value relative to market alternatives.

3.5.1. Testable Implications for Boundary Viability

- **Implication 1: Discounting and adoption**

Higher discount rates reduce the present value of delayed circular benefits, making boundary expansion less likely. Firms facing higher financing costs, greater uncertainty, or shorter planning horizons should therefore exhibit fewer circular internalization decisions and greater reliance on externalized arrangements.

- **Implication 2: Property rights in residuals**

Stronger and more clearly defined property rights over residual materials reduce coordination and bargaining costs, accelerating the transition to positive net savings under circular governance. Empirically, stronger residual property regimes should be associated with earlier and more persistent periods where $[S_1(t)]_+ > 0$.

- **Implication 3: Disposal pricing and baseline shift**

Higher landfill or disposal fees raise the cost of the baseline regime, increasing $S_1(t)$relative to $S_0(t)$. By shifting the cost baseline, disposal pricing expands the time interval over which circular boundary expansion generates positive net savings and satisfies the viability condition.

3.6. An Ideal of Coordination, Information, and the Emergence of Circular Markets

The genius of the market and pricing system is its amnesia. It does not need to know the full history of a thing to assign it value through prices. Much of the current path to circular economy in the literature threatens this simplicity by remembering too much, by burdening trade with *extensive* biography. There is an alternative to designing circular markets deliberately: not to impose markets with memory, *but to make forgetting expensive.*

Waste ceases to need an identity when its recovery has a market. Price absorbs biography; the signal carries the memory. The low-quality aluminium ingot that has been melted three times will simply trade for less versus the high-quality aluminium ingot that has been costly to recover. Quality, purity, and recoverability are translated into liquidity. Markets forget the details because the arithmetic remembers.

Reputation replaces record-keeping in the mature circular market. A firm that designs for disassembly or durability need not certify its virtue; it earns it in the service provision between resale and replacement. When products survive, their producers do too. When products decay too fast, the penalty arrives not solely through regulatory penalty but through loss of consumer confidence.

And so, the market remembers without remembering. It internalizes continuity the way it internalizes scarcity, through the steady pressure of knowledge transmission. Circularity *becomes marginally less anonymous than its linear predecessor through boundary expansion*, but infinitely more stable. In this order, the circular firm no longer bears the titanic burden of absolute total reformation. It operates as every successful firm always has by reading the price and surviving accordingly.

In the linear economy, the logic of circularity can emerge without ceremony. Consider steel. In a linear system, virgin ore is mined, smelted, formed, and discarded when a product's useful life ends and may be recovered, but outside the interest or care of the producing firm. Waste steel becomes a disposal cost, something to remove, not recover. Yet when energy and extraction costs rise, scrap becomes cheaper than ore. Foundries, acting from pure self-interest, begin to bid for clean, uncontaminated scrap. Price begins to encode quality. The market, impersonal as ever, rewards purity and penalizes wastefulness. Over time, producers adapt, they weld less, sort better, and standardize alloy types so their scrap commands a higher price. No moral enlightenment is required only arithmetic and incentives.

Reaching this stage does not require vast institutional scaffolding, only ***a legal framework that corrects the distortions which keep waste artificially cheap***. The most efficient levers are minimal but structurally critical: differential disposal pricing that reflects real external costs (*making landfilling expensive enough to render recovery profitable*); legal clarity establishing waste as property that can be owned, traded, and insured like any commodity; transparent markets for secondary materials, where grades and specifications are published and comparable. Additionally direct tax incentives for firms that engage in circular practice as the dominant disposition of their business and shared legal frameworks that define how the firms qualify for said circular incentives. These interventions are centres of gravity, levers that do not direct behaviour but remove friction, allowing circular price signals to propagate fully through the loop.

Today's recycling and resale systems are reactive, fragmented, and dependent on subsidies or moral appeal. They operate as appendages to a production system still aimed at throughput, not continuity. Prices are distorted by hidden costs: pollution, disposal, contamination so the market cannot coordinate on its own. In a truly mature circular market, those distortions collapse. Waste ceases to be an administrative burden and becomes a priced resource. Producers act on cost, not conscience in the mid to long term; consumers act on value, not virtue.

The alternative, of course, is to build a circular economy through perfect visibility rather than through price, to replace anonymity with traceability by design, to construct a world where every object carries its biography and every transaction its genealogy. The challenge of this approach aside from cost is scale. Too much traceability breeds friction, and friction is fatal to firms on the margin that may want to transition. Circularity built on visibility risks becoming an economy of surveillance, one that cannot escape its own paperwork, *killing the circular economy without transitioning it.*[8]

3.7. The Realpolitik of Circular Markets

Prices can transmit information through value, but it cannot create new values *ex nihilo*. A minimal grammar of quality must still exist, shared legal standards for purity, measurement, and certification that let buyers recognize what the price implies. Without this substrate of comparability, signals never materialize. The goal is not transparency through bureaucratic expansion, but interpretability through bureaucratic minimalism in the right places: a world where information is reliable and legible enough for price to act as translator, not stenographer.

The simplicity of the proposed policy fulcrums, differential disposal pricing, property rights in waste, shared legal frameworks clearly defining what it means to be circular and fiscal favourability for reuse belies the complexity of its implementation. To make waste expensive to forget is to add to or change the legal framework of the state. Disposal pricing demands measurement: property rights require registries; even tax incentives presume coordination between finance, environment, and trade ministries. Minimalism is not the same as ease. It means that every intervention must be structural and robust, not symbolic: *a few precise strokes that shift the boundary conditions of rational behaviour rather than the rhetoric of responsibility. The state's role is not to moralize circular markets but to lower the transaction costs of their function.*

What begins as a market correction matures, inevitably, into a new kind of economy. Once prices reflect the true cost of waste, circularity becomes a real economic discipline. Firms no longer scale by expansion alone but by recovery, by reclaiming, refining, and reinserting what would once have been lost. In this way, geography follows behaviour: recovery clusters form where circular firms or waste concentrates, and their success begins to redraw the economic landscape.

4. Toward a Decision Environment Theory of Circular Transition

Every theory reaches a point where description must give way to form. The circular economy has been described in metaphors, loops, cycles, ecosystems, but it is less formalized as a system of decision and constraint. What emerges here is not another manifesto of sustainability, but a microeconomic theory in which the circular firm is natural in markets within realistic ecological limits.

4.1. The Decision Environment

The defining resource constraint of the circular firm is no longer access to virgin material, but the ability to recover waste as material inputs and ensure product longevity across time. The firm's production function must therefore be written as a temporal system: inputs are not consumed but transformed, and outputs decay rather than disappear (Boulding, 1966; Georgescu-Roegen, 1971).

[8] Concerns about over-bureaucratization in circular economy governance can be interpreted through a transaction-cost lens. Graeber (2015) documents how modern regulatory systems tend to proliferate procedural requirements and compliance layers that increase administrative effort without proportionate coordination gains. Applied to circular markets, this suggests that highly detailed traceability regimes and certification architectures may raise coordination and verification costs to a degree that discourages firm entry, experimentation, and scaling. Where bureaucratic complexity substitutes for price-based coordination, circular activity risks remaining administratively managed rather than evolving into a self-sustaining market process.

In this environment, the firm's costs divide into three categories: fixed (technological and infrastructural), variable (processing, sorting, recovery), and coordination (trust, logistics, verification). All of which evolve over time. Short-run inefficiency becomes an investment in long-run viability. The firm that survives is not the one that maximizes profit instantly, but the one that maintains positive profit through adaptation (Alchian, 1950).

4.2. The Logic of the Decision Environment

Fixed costs establish an initial constraint that renders early-stage circular activity relatively inefficient, while variable and coordination costs in **Figure 3A** converge as learning, scale, and organizational alignment take place. Circularity becomes economically viable only once declining variable costs and stabilized coordination costs jointly fall below / plateau at the fixed-cost baseline, at which point surplus emerges endogenously from the production structure itself. The firm's realized value is thus the accumulation of positive net savings after this threshold is crossed, discounted over time to reflect uncertainty and opportunity cost.[9]

4.2.1. Circular Firm: Dynamic NPV Realization

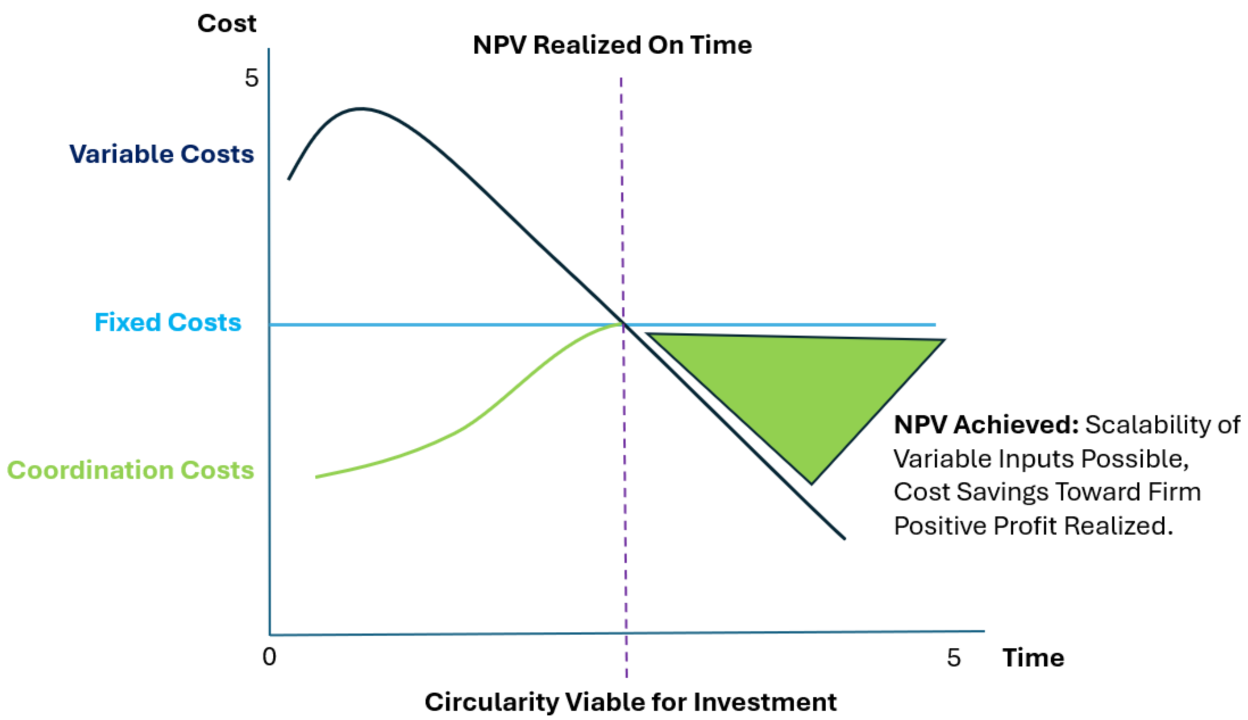

Figure 3A. Circularity Viable: The Circular Viability Curve

The integral below is illustrative of the continuous accumulation of discounted net savings once circular operations become cost positive.

$$\boldsymbol{NPVachieved} = \int_0^{T} e^{\wedge}(-rt)\,[S(t)]_+\,dt$$

The firm creates value only after circular operations reduce costs below the fixed baseline, and the total economic benefit is the discounted sum of those savings per unit produced or service provided over time.

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[9] Scaling positive net savings means circular operations lower unit costs and cash outflows predictably as volume increases, with recovered inputs reliably displacing virgin materials. Coordination and overhead costs stabilize rather than rise with scale, allowing fixed investments in design and logistics to be amortized across multiple cycles. At this point, circular initiatives are evaluated and funded under standard capital discipline using discounted cash-flow criteria, not special sustainability allowances.

$S(t)$ - net savings at time t, defined as fixed costs minus the sum of variable and coordination costs.

$[S(t)]_+$- the positive part of net savings, indicating that only periods in which savings are positive contribute to value creation; periods of loss generate no realized value.

e^{-rt}- the discount factor, accounting for the time value of money and risk as savings are realized further into the future.

dt - an infinitesimal unit of time, signifying that value is accumulated continuously as the firm's cost structure evolves.

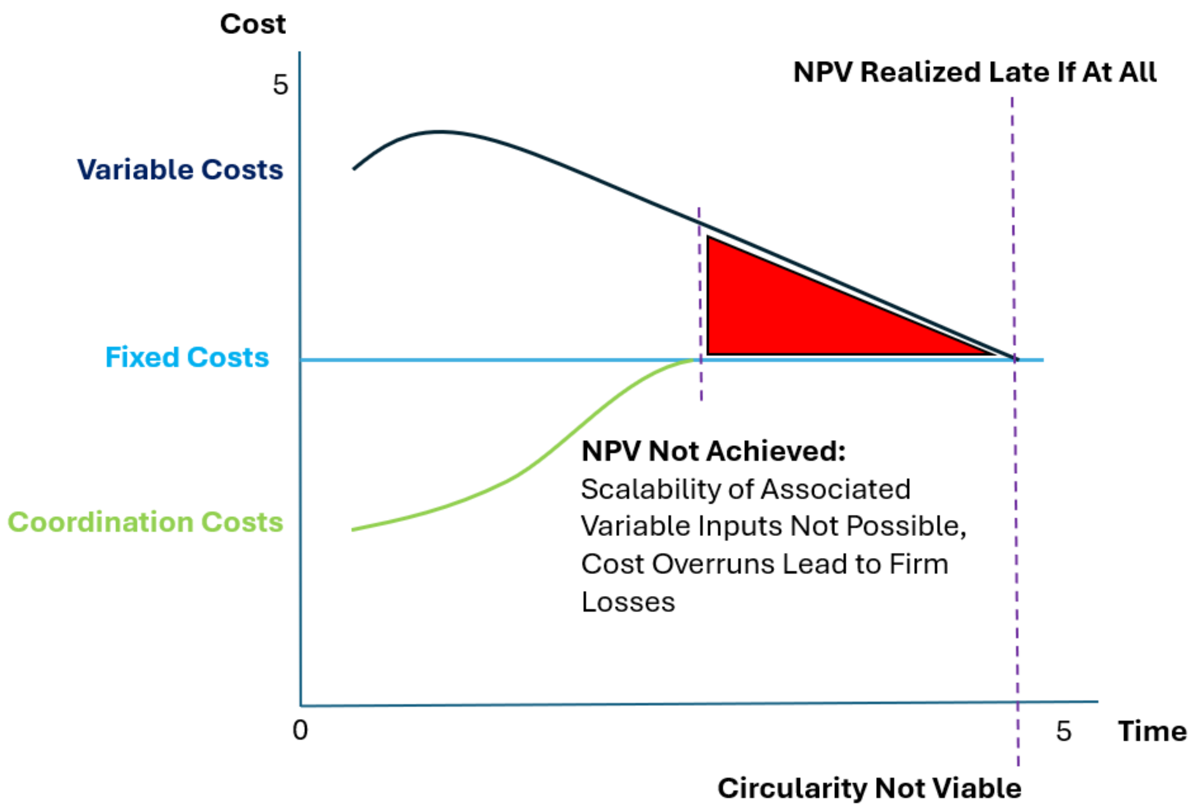

Figure 3B. Circularity Not Viable: The Circular Viability Curve

In **Figure 3B** circularity fails to achieve positive net present value when variable and coordination costs do not decline sufficiently, or early enough, to overcome fixed costs and discounting, resulting in accumulated losses over the firm's planning horizon.

In the viable case, circular investment functions as a structural transition: declining variable costs and stabilizing coordination costs cross below the fixed-cost baseline early enough for positive net savings to accumulate and compound through time. In the non-viable case shown here, that transition fails to materialize. Although costs may converge toward the fixed baseline, the convergence is delayed, incomplete, or unstable, such that any prospective surplus is outweighed by discounting and ongoing cost overruns.

Timing is critical: efficiency that arrives too late cannot compensate for losses incurred early, making eventual savings economically irrelevant. A viable circular initiative demonstrates a visible and durable transition in which operating costs fall below the fixed baseline and remain there as activity increases. Isolated or short-lived savings do not constitute success; value emerges only when savings persist and strengthen with scale. Coordination challenges should peak early and stabilize, if organizational friction continues to rise, the model is structurally misaligned and requires redesign rather than patience.

4.2.2. Testable Implications of the Circular Decision Logic

- **Implication 1 (Timing Dominance over Long-Run Efficiency).**

Circular investments are more likely to be viable when variable and coordination costs decline or flatten early rather than merely substantially. Holding eventual cost levels constant, firms whose circular initiatives achieve cost reductions sooner are more likely to realize positive net present value than firms whose cost convergence occurs later. Empirically, initiatives with similar long-run unit costs will exhibit divergent outcomes depending on how quickly they cross the fixed-cost baseline.

- **Implication 2 (Persistence of Savings over Episodic Gains).**

Durable cost-positive regimes generate value, while intermittent or volatile savings do not. Circular initiatives that briefly enter positive net savings but fail to maintain them over time will exhibit lower realized value than initiatives with smaller but stable cost advantages. Empirically, firms with smoother and more persistent post-threshold cost trajectories should outperform firms with higher variance in variable or coordination costs, even when average savings appear similar.

- **Implication 3 (Early Coordination Peak as a Viability Signal).**

Viable circular initiatives exhibit coordination costs that peak early and stabilize, while non-viable initiatives exhibit rising or unstable coordination burdens. In successful circular transitions, organizational and coordination costs rise sharply during early experimentation but flatten as routines, standards, and scale emerge.

4.3. Practical Applications Toward Circularity

How can the decision environment be used in practice? Its relevance extends to three primary groups: circular economy (CE) scholars, firm executives and managers, and policy and legal institutions. For CE scholars, the decision environment functions as a framing device that reconnects circular economy analysis with established economic theory, addressing a gap in the literature by demonstrating how concepts of production structure, coordination, and firm boundaries can be systematically integrated into CE theory, extending lines of inquiry associated with Coase and Alchian.

For firms, the decision environment reframes circularity as a structural problem rather than a discrete business model choice. Whether for new enterprises or incumbent firms transitioning from linear production, circular integration becomes viable where firms adopt a positive-profit standard oriented toward long-run survivability rather than short-term maximization. In practical terms, the decision environment is applied through incremental changes to the production structure, recognizing that capital assets are specialized, updated sequentially, and characterized by high costs and long payback periods. It provides a basis for evaluating circular investments at the level of projects and business cases, using dynamic net present value shown in **Table 2** or equivalent forward-looking analyses that incorporate circular conditions such as stratified inputs, uncertain recovery rates, and evolving market co-creation.

Table 2. Dynamic NPV Example

NPV Line Item	Traditional NPV (Linear Firm)	Circular NPV (Circular Firm)
1. Initial Investment (CAPEX)	Single-purpose fixed asset: Plant, equipment, IT	CE Enabling Assets: Production assets + reverse logistics, recovery, and standards (long-dated capital that reshapes future costs)
2. Operating Cash Flows	Static operating margin: Homogeneous input costs	Input-linked cash flow stream: virgin inputs + recoverable inputs treated as quality-graded cost instruments
3. Discount Rate	Exogenous risk premium: Time value + generic project risk	Option-discount interaction: Same rate, but value depends on how fast options are exercised as a risk driver
4. Time Horizon	Finite forecast window: Administrative planning choice	Option maturity period: Defines how long learning and coordination options have to pay off
5. Terminal Value	Exit multiple / perpetuity of returns: Assumes unchanged structure	Continuity asset value: Accounts for stabilized access to secondary inputs and reduced future volatility / increased savings.

Assuming that the Circular NPV can be realized for a project, the boundary of the firm expands to incorporate the workstream into the production structure. This is where the firm begins in the entry stage with sequence identification and action toward circular transformation.

The decision environment functions as an analytical overlay on a firm's horizontal and vertical integrations, defined by the distance between the linear economy (LE) firm boundary and the circular economy (CE) firm boundary. Within this space, circular initiatives are treated as structural interventions into the production structure whose placement and sequencing shape the trajectory and completeness of transition. When introduced coherently, such interventions enable consistent incremental movement toward a more circular disposition; when introduced out of sequence, they tend to produce hybrid configurations characterized by long return horizons and extended restructuring periods.

The decision environment is used primarily to assess project feasibility rather than to prescribe transformation pathways. In emergent circular firms, it identifies projects that expand the CE firm boundary; in hybrid firms, it additionally highlights circular integrations capable of replacing linear processes while maintaining positive profitability. Feasibility is evaluated through forward-looking investment analysis, applied at both portfolio and project levels. Projects that meet these criteria are interpreted as viable components of the CE firm boundary, while those that do not remain external.

The decision environment is therefore intentionally limited in scope. It assesses the feasibility of circular transformation under a positive-profit constraint but does not determine the sequencing or prioritization of changes within the production structure, which remain contingent on firm-specific conditions and managerial judgment.

4.4.1. Decision Environment for Circular Transition

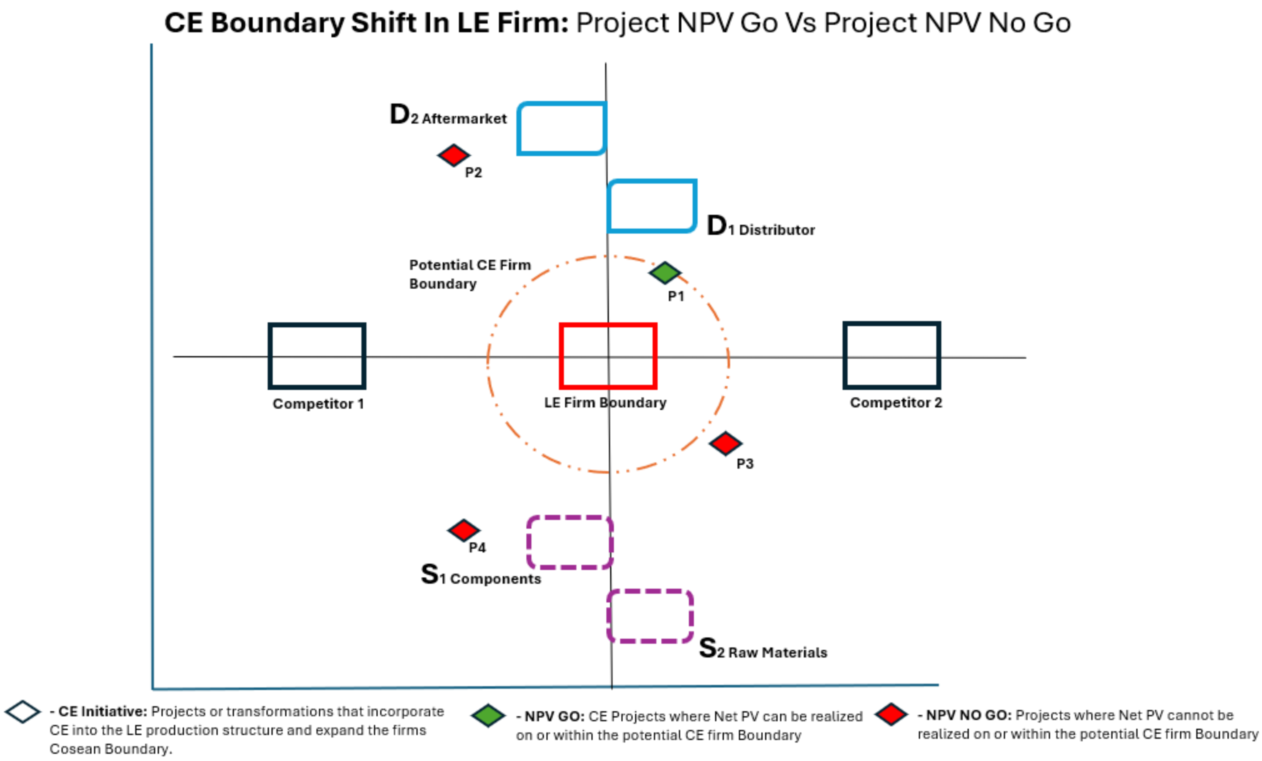

Figure 4A. CE Environment & Transformation Project Feasibility

Figure 4A illustrates the decision environment and the challenge of circular transition. In the current environment, only Project 1 (P1) meets the NPV-Go threshold, allowing only a partial transition. Although Project 3 (P3) lies closer to NPV-Go status within the circular boundary than Project 2 (P2), P3 is dependent on the prior integration of P2. Because sequencing over time matters, prioritizing P3 perhaps due to temporary advantages such as strategic alliances risks stalling the broader transition. In such cases, the firm becomes locked into a hybrid configuration in which P1 and P3 are integrated, while P2 and P4 remain economically infeasible due to the additional restructuring costs required to retrofit the production structure. Even under otherwise favourable conditions, these costs can keep later-stage projects below the NPV-Go threshold.

A practical example illustrates this logic. Consider a production structure in which Machine X refines raw material (RX), feeds it into Process Y, and produces Product Z, which is then integrated into a downstream section of production. Substituting RX with a recoverable substitute (RS) cannot occur in isolation. Due to capital complementarity and specialization, Machine X must be replaced with Machine S, which processes RS instead of RX. This substitution alters downstream outputs, requiring Process Y to be modified to (Y1) and transforming Product Z into a variant (Z1). These changes then propagate into the subsequent production section, which must also adapt to accommodate the altered output.

This cascading adjustment illustrates the structural nature of circular transition. The greater the ripple through the production structure, the more extensive and costly the required adaptations become. These rising transition costs underscore the importance of maintaining positive profitability during circular integration, as firms must absorb restructuring burdens while preserving economic viability.[10]

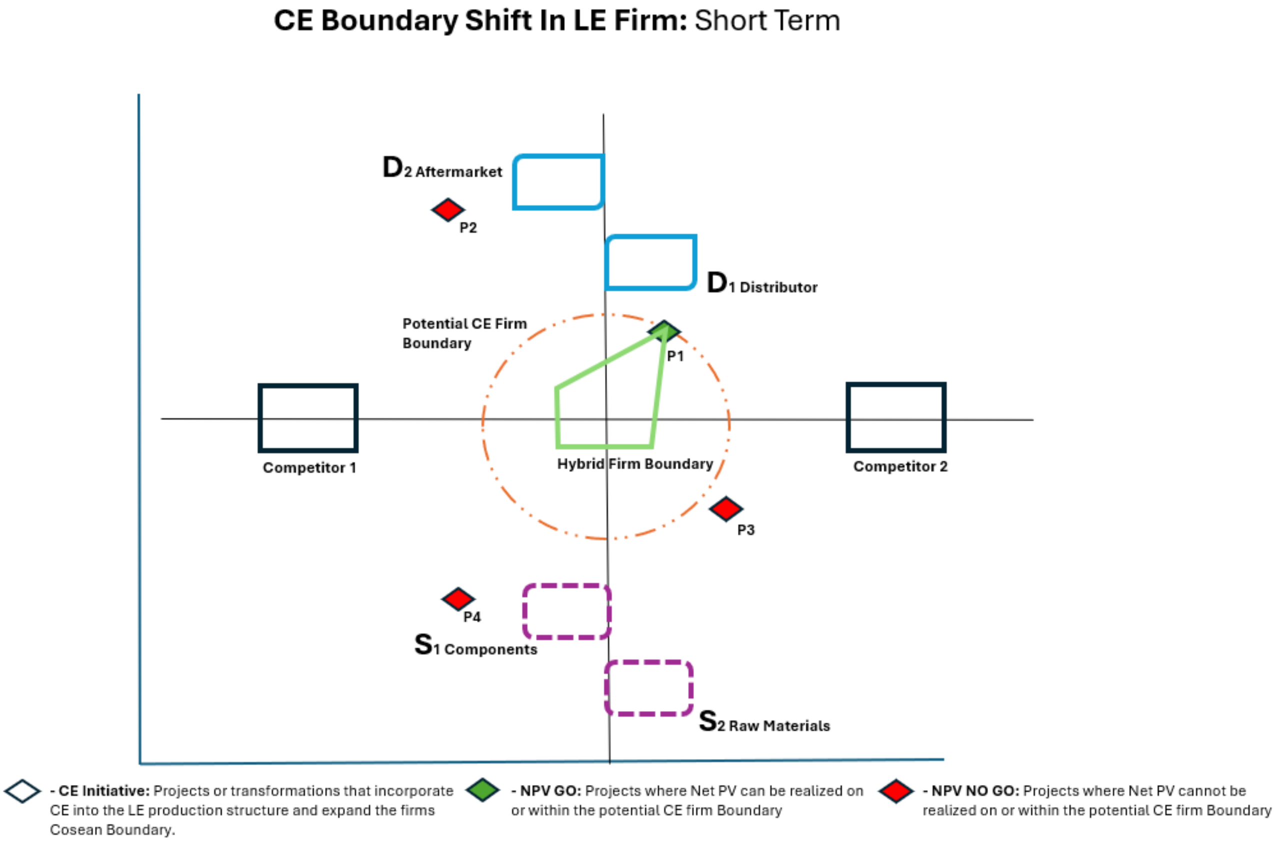

Figure 4B. Firm Short-Term[11]

Where a firm can adopt any circular integration, this represents a clear gain for CE transition. Within the decision environment, however, the objective is not merely to identify a single viable integration, but to expand the range of circular options that meet positive-profit criteria. As illustrated in **Figure 4B** (Firm Short-Term), the presence of any initiative within the NPV-Go region is a favourable outcome, particularly when that initiative corresponds to an early-stage integration rather than a later, more dependent one.

Figure 4C (Firm Long-Term) depicts the ideal case in which all economically optimal circular transformations fall within reach over a certain time period. At this point, the central challenge shifts from feasibility to sequencing. Circular transition moves beyond the decision environment into a problem of

[10] Changes to a production structure can ripple forward and backward through the subject structure.

[11] This short-term picture aligns with 1A: Circularity Costs in Firm Short-Term on page 9. Additionally, it would represent a 1 on the X axis time scale of a portfolio level view of 3-A Circularity Viable: The Circular Viability Curve.

ordering interdependent projects, where the task is no longer to establish whether value-creating circular opportunities exist, but to determine how they can be sequenced so that production structure remains coordinated, positive profitability is maintained, and each step constitutes a stable expansion of the firm's circular boundary.

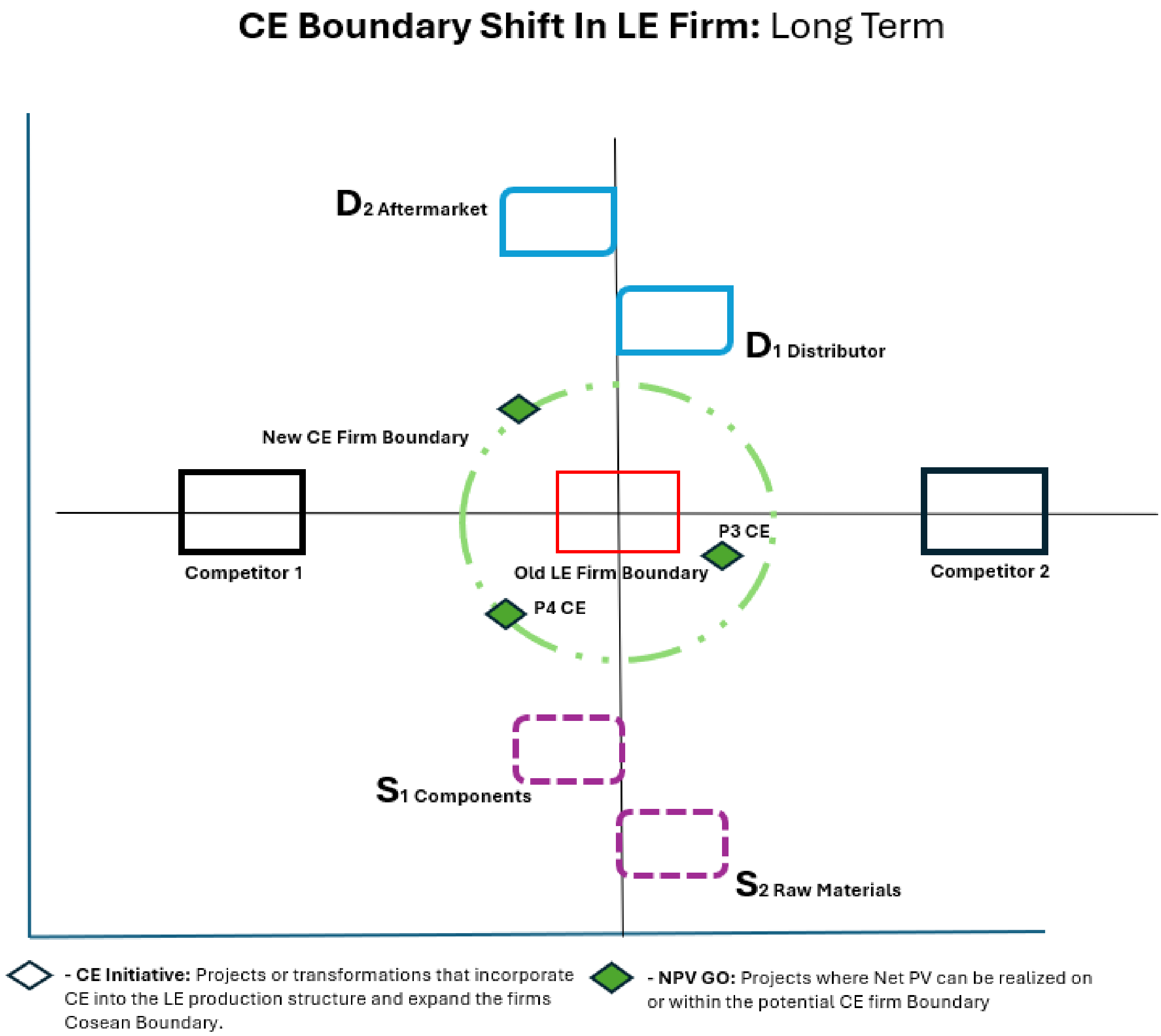

Figure 4C. Firm Long-Term[12]

Managers and executives should aim to integrate as many circular economy (CE) transformations that meet NPV-Go criteria into the production structure as possible. To maintain positive profitability, such integrations are necessarily incremental. Once all feasible projects within the decision environment have been incorporated, over a select period, the firm's circular transition from early adoption through long-term maturity can be considered complete.

Projects outside the CE firm boundary will be the responsibility of intermediary or emergent firms to address in a mature circular economy. However, in the transition, assuming immaturity, the remaining problem is how projects initially outside the feasible CE firm boundary are brought within it. This is the feasibility challenge of transitioning from linear to circular production, and it highlights the role of policy and legal

[12] This long-term picture aligns with 2B: Circularity Cost in Firm Long-Term page 10. Additionally, it would represent a 4/5 on the X axis time scale of a portfolio level view of 3-A Circularity Viable: The Circular Viability Curve.

institutions as the third key users of decision environment theory. Institutional actions shape the decision environment itself, expanding or constraining project viability and altering relationships among firms and other actors. Two mechanisms are particularly relevant: pre-competitive partnerships and policy or legal interventions that affect key CE impact fulcrums.

Pre-competitive partnerships, illustrated in **Figure 4D**, operate at the project level by dispersing coordination and transaction costs across stakeholders, allowing some circular integrations to shift from NPV-**No Go** to NPV-**Go** status and be incorporated into hybrid firm structures. Such arrangements function as second-best responses to institutional deficiencies, particularly weak property rights and price formation in waste and secondary material markets (Coase, 1960; Demsetz, 1967). While they temporarily mitigate risks by collectivizing uncertainty, they can also exclude competitors, suppress price discovery, weaken investment incentives, and substitute negotiated coordination for market signals (Williamson, 1985). As a result, reliance on pre-competitive coordination risks entrenching a permanently transitional regime that inhibits the scaling and maturation of circular markets.

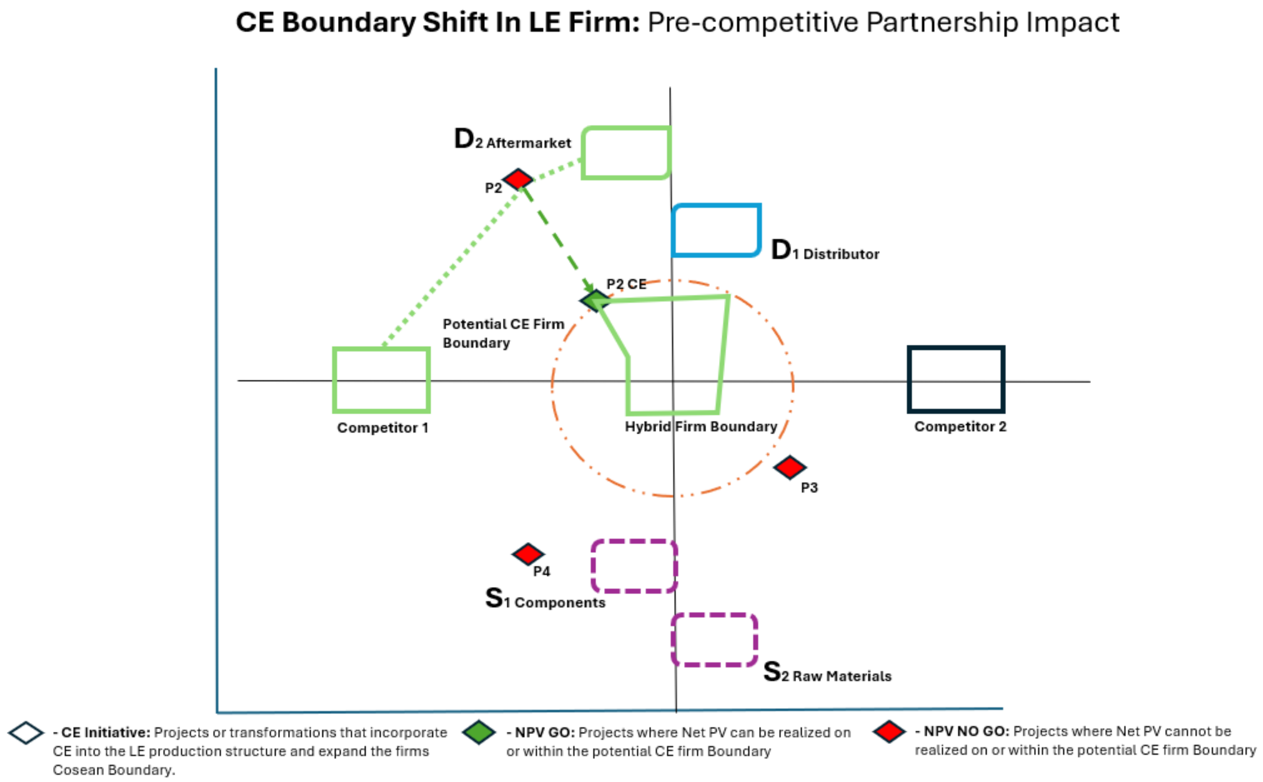

Figure 4D. Pre-Competitive Partnership Impact

An alternative to pre-competitive coalitions is a focus on policy and legal fulcrums, particularly the development of robust property rights and effective price formation in waste and secondary input markets. Unlike pre-competitive partnerships, which alter the decision environment selectively around specific projects or workstreams, policy and legal reforms reshape the decision environment for all firms simultaneously. Their impact is therefore systemic rather than case specific.

The difference in impact is significant, shown in **Figure 4E**. Targeted reforms do more than make the decision environment broadly supportive of circular transition; they expand the potential CE firm boundary and bring sequential circular transformations within reach at the same time. In this sense, policy and legal fulcrums enable circular integration to scale beyond individual projects and firms, accelerating the maturation of circular markets.

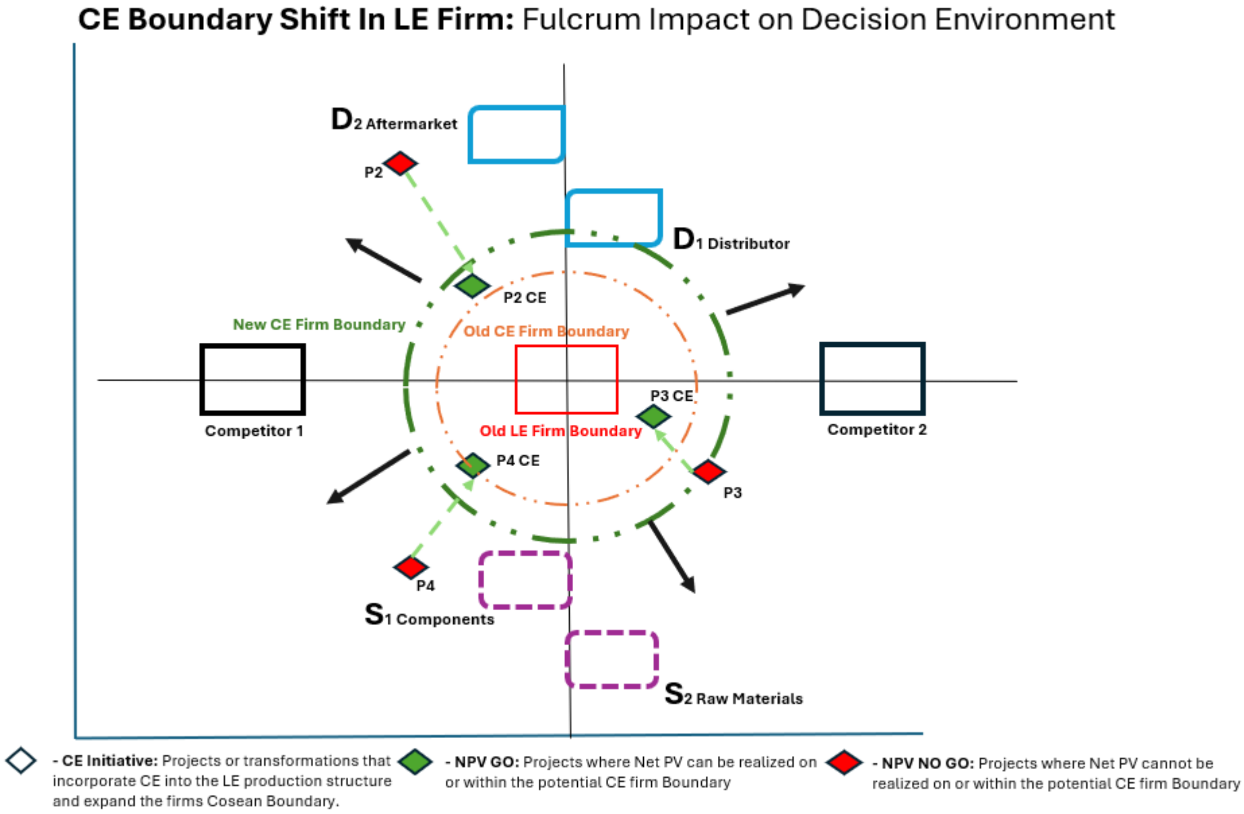

Figure 4E. Fulcrum Impact on the Decision Environment

Here we see an illustration of the significance of focusing on the proposed policy fulcrums to shape the economic landscape. A dynamic impact to firms across broad swaths of the economy. Focusing on fulcrum impact benefits firms in three ways to achieve circular transition:

1. **Expanded choice:** Policy fulcrums bring previously cost-prohibitive projects within the CE firm boundary by reducing the relative cost of circular integration compared to linear practice.
2. **Boundary Expansion:** They extend the Coasean boundaries of the firm, increasing the scope for cost-effective circular regimes to be integrated into legacy production structures.
3. **Emergence of Intermediaries and Cluster Economies:** When boundary expansion occurs broadly rather than in a targeted manner, firm boundaries naturally begin to overlap (D1 in the diagram). This creates entry incentives (demand shifts) for intermediary firms to enter the market. Additionally, coordination increasingly shifts toward market incentives and price signals, enabling circular relationships to form through decentralized exchange rather than project-specific contracting, firms may then more easily cluster around newly cost-efficient industries and workstreams.

The essential takeaway is that policy and legal fulcrums may exert a significantly deeper and broader impact on circular economy transition than project-specific or workstream approaches such as pre-competitive partnerships. A natural next step is to apply the decision environment lens to specific industries including fast fashion, perishable commodities, technological products, and highly regulated sectors to examine how differences in production structure, asset lifetimes, regulatory intensity, and waste persistence condition the firm’s decision environment and require adaptation of the proposed decision logic.

Such analysis can clarify why some industries reach NPV-Go thresholds and expand circular firm boundaries more rapidly than others, informing where policy and legal efforts are most effective. At the firm level, sectoral comparison can also reveal recurring project types such as reverse logistics or material recovery that generate transferable insights into circular opportunities and risks across industries.

5. Conclusion

The circular firm does not reject the linear economy; it completes it. Where linear markets achieved efficiency by intensifying productivity, circular markets achieve efficiency by extending continuity. Success is no longer defined by how rapidly resources move through the system, but by how long productive value can be sustained, renewed, and adapted in the presence of material limits. Persistence, rather than throughput, becomes the relevant measure of economic fitness.

Nor does the circular firm operate in isolation. It functions as the cellular unit of a broader economic ecosystem whose growth is less expansive and more accretive. Regions organized around such firms deepen rather than sprawl, compounding material value, institutional knowledge, and productive resilience over time. What begins as the revaluation of waste evolves into a reorganization of production itself: Networks of firms linked not by extraction and disposal, but by recovery, reintegration, and mutual maintenance. In this sense, a theory of the circular firm becomes a theory of circular development, one in which micro-level survival aggregates into macro-level stability, and where the recognition of waste as property gives rise to the persistence of goods as both product and service within a finite economic world.

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Declarations

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