

## ECONOMIC SOCIOLOGY

# Financialization impedes climate change mitigation: Evidence from the early American solar industry

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The article investigates how financialization impedes climate change mitigation by examining its effects on the early history of one low-carbon industry, solar photovoltaics in the United States. The industry grew rapidly in the 1970s, as large financial conglomerates acquired independent firms. While providing needed financial support, conglomerates changed the focus from existing markets in consumer applications toward a future utility market that never materialized. Concentration of the industry also left it vulnerable to the corporate restructuring of the 1980s, when the conglomerates were dismantled and solar divisions were pared back or sold off to foreign firms. Both the move toward conglomeration, when corporations became managed as stock portfolios, and its subsequent reversal were the result of increased financial dominance over corporate governance. The American case is contrasted with the more successful case of Japan, where these changes to corporate governance did not occur. Insulated from shareholder pressure and financial turbulence, Japanese photovoltaics manufacturers continued to expand investment throughout the 1980s when their American rivals were cutting back. The study is informed by Joseph Schumpeter's theory of creative destruction and Hyman Minsky's theory of financialization, along with economic sociology. By highlighting the tenuous and conflicting relation between finance and production that shaped the early history of the photovoltaics industry, the article raises doubts about the prevailing approach to mitigate climate change through carbon pricing. Given the uncertainty of innovation and the ease of speculation, it will do little to spur low-carbon technology development without financial structures supporting patient capital.

## INTRODUCTION

Reducing carbon emissions to safe levels means replacing the present industrial system. Low-carbon technologies, which are currently marginal, need to become competitive enough to mount a wave of “creative destruction,” to use Joseph Schumpeter's (1) term, sweeping away fossil fuels. Technological revolutions normally occur when profit opportunities in established industries are exhausted, but this one would have to occur much sooner, engineered through state policy. Ultimately, however, state policy is only as effective as the innovative capacity of private firms. It is therefore concerning that this capacity appears to have been weakened by financialization (2, 3). In the past 40 to 50 years, advanced economies have become increasingly subjected to the vicissitudes of financial markets. Ever-larger amounts of credit have been created to trade existing assets such as real estate rather than productive investments. The most visible effect of this process has been a series of asset bubbles, followed by painful periods of deleveraging [(4), p. 62]. As John Maynard Keynes recognized, capitalist economies always contain the capacity for both “enterprise” and “speculation,” and if left unchecked, the latter will come to dominate over the former. Economists at the Bank for International Settlements have found that financialization harms innovative firms, which operate by creating intangible future assets that are difficult to collateralize (5). This shift has also changed corporate governance, bringing an increase of “financial controllers in the management of corporations” and of “the stock market as a market for corporate control in determining corporate strategies” (6). As a result, firms have become less oriented toward investing to improve their long-term performance and more oriented toward enriching their managers and investors in the short run (3). Reinforced by managerial incentives, increasing amounts of profits are spent on dividends and stock buybacks, leaving less for investment in long-term technological development (7). While the financial sector has grown as a share of advanced

economies, nonfinancial firms have become financialized, drawing profits from financial activities and orienting their strategy toward maximizing the value of their financial assets instead of productive ones. Hyman Minsky feared that this process, already visible by the 1980s, would not only cause fragility but also would undermine “the capital development of the economy,” that is, the development of its productive capabilities (8). Instead of serving industrial development, finance had come to serve itself.

Finance is an essential component of industrial change because it allows technologies to be developed before they can generate a return. But if finance no longer serves industrial change but instead prioritizes rent-seeking (seeking to increase its share of existing wealth without creating new sources of wealth), creative destruction of the present carbon-intensive industrial system cannot occur. The aim of this article is to investigate this issue through a study of the emergence of one low-carbon industry, solar photovoltaics (PV) in the United States. The focus is on the period after the first oil shock in 1973 until the end of the 1980s. The case is contrasted with the more successful development of the industry in Japan. In the late 1970s, American firms held 90% of the global market share; by 2005, it had declined to under 10%, whereas the Japanese share had risen to almost 50% (9). Changes to corporate governance and organization brought by financialization are identified as major causes of the difference in outcome.

This study is informed by Schumpeter's theory of creative destruction, which remains the most useful tool for understanding industrial change; it also is influenced by the financial insights of Schumpeter's student, Hyman Minsky. Economic sociology will also be applied to analyze the central role of uncertainty in innovation and the social mechanisms to overcome uncertainty in concrete social and institutional conditions. These insights will be outlined in a rather lengthy theoretical section. The goal is to provide a coherent synthesis of three large and synergistic bodies of work, ranging from a stylized view of the microlevel interactions between entrepreneurs and financiers (and workers) up to the macrolevel of institutional arrangements of comparative capitalisms. Beyond shedding light on the emergence of the industry under study,

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this synthesis might be used to guide other similar studies. A more comprehensive study would include an in-depth analysis of industrial policy and the social forces behind it, but as the study will show, changes to corporate governance were major determinants of the outcome because industrial policy was dominated by large firms in both countries.

The article concludes with a discussion of implications for low-carbon industry development in the future. The study highlights the tenuous and conflicting relationship between finance and production, calling into question proposals to mitigate climate change based on the assumption of a harmonious relationship. Carbon pricing rests on the idea that, if government policy makes one industry uncompetitive, finance will automatically flow to another. This article indicates that such a result can only be expected under certain conditions, which do not appear to apply in the advanced world at the present.

### Finance and innovation

Finance is an integral component of innovation because it allows technologies to be paid for before they exist. It acts as a bridge between the expectations of future profit and the ability to realize it by assembling the needed resources in the present. By creating new purchasing power in the process, finance also expands the money in circulation, thereby allowing aggregate profits to exist (10). This makes finance the defining feature of capitalism, a system that evolves through continuous forward-looking investment in new capabilities, motivated by the prospect of using them to produce output for profit. When private and public banking merged into a coherent financial system in early modern Europe, it created the “infrastructural power” needed for a transition from feudalism to capitalism (11). Pools of safe financial claims to real wealth enabled the application of long-term rational calculation to industrial production [what Weber defined as the essence of capitalism (12)], and the widespread circulation of these claims created markets where profits from this rationalized production could be realized.

Joseph Schumpeter noted that introducing a financial sphere into a static economy makes it dynamic (13). It orients the economy toward the future, changing calculations of economic value from including only existing resources to also including those resources that might be expected to exist in the future. As a result, the horizon opens up to potentially infinite possibilities for technological advances. This shift also introduces a certain fictitious quality to the economy because the future is unknowable and expectations will inevitably diverge from actual outcomes. Financial claims correspond to the value of real assets, but the correspondence is never absolute. This separation between present and future value that finance introduces is what gives capitalism its instability. Schumpeter saw that finance destabilizes the economy by enabling entrepreneurs to introduce innovations that cause creative destruction. However, it can also be destabilizing in a different way. Finance has a tendency to decouple from production and fuel asset bubbles instead of industrial change. It then becomes a tool of value extraction instead of creation, a process that we now recognize as financialization. Schumpeter had a lucid analysis of the role of finance in production, but the full implications were better explored by his student Hyman Minsky. The theories of both will be used to guide the empirical study. The future orientation of technological development also calls for an inclusion of economic sociology into the analysis to account for the formation of perceptions and social mechanisms to overcome uncertainty. Sociology is also needed to account for the fact that capitalism, as Schumpeter and Minsky insisted, is an evolutionary system that interacts with changing institutions over time. What follows is a summary of Schumpeter’s views of the role of fi-

nance in industrial development, Minsky’s additions, and a set of sociological tools to situate their universal logic in concrete social and institutional settings.

Because it takes time to assemble innovations before they can generate a return, Schumpeter argued that the process must be paid for in advance. The mechanism that makes this possible is credit. That is why Schumpeter defined capitalism as a system “in which innovations are carried out by means of borrowed money” [(14), p. 223]. He viewed the financial system as the “headquarters of capitalism,” determining which technologies are allowed to emerge [(15), chapter 3]. Capitalist production depends upon the interaction of two roles, the financier and the entrepreneur. The financier owns monetary claims to real wealth and operates by leveraging them in pursuit of more claims. The entrepreneur operates by producing the real wealth that makes financial claims valuable in the first place. In Schumpeter’s view of capitalism, financiers create credit for entrepreneurs, who spend it into existence in the act of investment; the bank notes circulate as money throughout the economy and end up as profit on the balance sheets of the most innovative entrepreneurs, allowing them to repay the debt. If there is money left, they can plow it back into further innovation, repeating the circuit on a larger scale. An expanded market share can act as a staging ground for increasingly capital-intensive innovation, creating barriers to entry for new entrepreneurs; however, as long as these have access to credit, they can introduce innovations that make the technologies of incumbent firms obsolete. This system of decentralized credit creation for innovation and continuously reinvested profits makes for a highly dynamic economy in which the means of production are continuously revolutionized.

In Schumpeter’s view, finance is subordinated to production. He built his dynamic theory of capitalism by introducing a financial sphere into the static economy of Leon Walras and never abandoned Walras’ model of an economy in which all productive resources were fully used (16). Hyman Minsky was able to advance on this view by incorporating crucial insights from John Maynard Keynes (16). Keynes argued that the existence of money as a store of wealth allows capitalists to leave productive resources unused. The traditional economy has only one price level for consumption goods. In Schumpeter’s theory, one can also find a price level for capital goods, that is, machinery and plant, which are expected to produce the consumption (and capital) goods of the future. In Keynes’s view, a capitalist economy also has a separate price level for financial assets. The difference in price between capital and financial assets determines real investment. When the expected return on capital goods exceeds the return on financial assets (that is, when demand is strong), capitalists will choose investment. When the expected return drops below the expected return on financial assets, capitalists will hoard their cash or spend it bidding up the value of financial assets. Because investment becomes the incomes that generate demand, the process is self-reinforcing.

Keynes differentiated between “enterprise” and “speculation”; the organization of money markets determines which one will prevail. “When the capital development of a country becomes the by-product of the activities of a casino,” he argued, “the job is likely to be ill done” (17). Minsky went on to explore what happened when innovation within the financial sphere itself causes it to decouple from production, spinning off into a self-referential loop of speculation (18). Even if the financial system begins as subordinated to production, financial innovators will find easier ways to make money. If left unchecked, innovative and profit-seeking financiers will break free of constraints and turn to speculation. Thus, finance becomes an instrument of rent-seeking.

Hence, what is missing from Schumpeter's theory is the fact that innovation is not the only use for which credit can be created: It can also be created to buy existing assets, in which case it does not fuel creative destruction but asset bubbles. There is also a limit to how much profit firms can reinvest. Production under capitalism is carried out for profit, and some point in the circuit profit will be extracted from the enterprise to be stored as liquid wealth. Only if capitalists are as austere as the monk-like toilers of Max Weber's *The Protestant Ethic and the Spirit of Capitalism*, and as confident in the future as to keep no amount of their wealth in cash, would they reinvest all their profits in production. As Keynes famously recognized (19), the common practice of storing wealth in cash and existing assets leaves real resources in the economy unused. As long as hoarding and speculation are available as options to financiers, their willingness to invest in innovation is limited. It is safer to live off the income streams of past investments, as "rentiers." A fully production-oriented economy is only possible if the financial component of capitalism is entirely subordinated to the entrepreneurial function, in which case it might no longer be recognizable as capitalism at all, but rather a centrally planned economy where decentralized financial decisions are curtailed.

Compared to the safety of lending for existing assets, innovation is an uncertain activity that prudent financiers tend to avoid. They are particularly unlikely to finance new and unproven entrepreneurs who face powerful competition from incumbent firms. Established firms can use retained earnings to innovate but tend to do so in ways that build on their existing capabilities, not in ways that make them obsolete. Innovation is rarely economically rational; as the economist and venture capitalist William Janeway puts it, it is dependent on "sources of funding that are decoupled from economic concern" (20). In the early stage, this usually means the state, which is free from financial constraints and guided by noneconomic goals such as national security (or hopefully, if under sufficient popular pressure, concern about climate change). At a later stage, financially unconcerned sources of funding may also include irrationally exuberant investors caught up in the speculative manias, which often surround new technologies. Hence, while speculation undermines creative destruction when it involves existing assets, a certain amount of it that is directed at new technologies is often necessary for it to take off. Neo-Schumpeterian economist Carlota Perez ascribes a certain temporal logic to the process: Financial capital tends to back new technology in the deployment phase, often creating a bubble that draws in sufficient resources for the technology to succeed. When profit opportunities are exhausted, it leaves to seek out new ones, which may include innovations.

In empirical studies, the universal logic of this model needs to be augmented with contextual detail. Whether financiers invest in creative destruction or not depends on the opportunities and constraints afforded them by specific institutional arrangements. Both Schumpeter and Minsky insisted that capitalism is an evolutionary system that adapts to institutional change. As Schumpeter stressed, economic sociology is therefore needed as a "bridge between theory and history" (21).

Another reason to view creative destruction through a sociological frame is the inherently uncertain nature of innovation and the centrality that perceptions of the future this entails. As game theory indicates, isolated individuals acting under uncertainty lead to suboptimal "prisoner's dilemma"-type outcomes. Uncertainty compels actors to adopt a prosocial orientation, turning market transactions into hierarchical transactions and limiting transactions to known parties and those with a reputable standing, among others (22). Interaction is made less uncertain through "social devices" such as habits, institutions, organiza-

tional structures, and outright domination (23, 24). Because the future is unknowable, investment decisions are always made on the subjective basis of confidence in the future, what Keynes called "animal spirits." Routine investments can be made by extrapolating past trends into the future, but investments in innovation must be based on more elaborate "fictional constructions" of future states (24). These are constructed by the various actors involved in the innovation process and must be shared by them if the innovation is to succeed.

The collective nature of innovation calls for a relational perspective, in which actors are analyzed not only on the basis of their individual characteristics but also by how they relate to each other. This applies to the various actors needed to cooperate in the innovation process, beginning with the entrepreneur and the financier. If they succeed in turning the venture into an enterprise, they must also resolve the tension between manager and employee. The tension within the capitalist class, between the entrepreneur and the financier, and between capital as a whole and labor also interact with each other in institution-specific ways.

The relational perspective is also needed to analyze competition between firms. Creative destruction is a power struggle between incumbents and challengers, which devise strategies by taking each other's presumed actions into account. The power balance is observed by financiers, who restrict finance to what they perceive to be the winning side. As Weber argued, finance is a weapon in the struggle for economic existence (25).

As the guarantor of the financial system and arbiter of market competition, the state plays an inescapable role in creative destruction. States may keep financial flows under strict control or allow financialization to proceed unhindered. The state is also a major source of spending and often sets the direction of innovation through industrial policy. The points made above will be elaborated in a series of propositions to guide the empirical study.

### Proposition 1: Innovation is uncertain

Innovation is, by definition, an uncertain activity whose outcome is unknowable. For financiers,

There is uncertainty about the talent of the entrepreneur, the market need for the product, the development of a saleable product, the raising of second-round financing for working capital and expansion; the manufacturing of the product, competitors' responses, and government policies [(26), p. 137].

Decisions to invest in innovation can therefore not be made on the basis of probabilistic calculation. As Jens Beckert argues, they must be based on fictional constructions of the future (24). These are socially constructed, if only in the sense that they must be shared to be realized. Collectively held expectations create the certitude necessary to commit resources to uncertain projects. As long as they do not stray too far from real technological constraints, they can be self-fulfilling.

New industries begin as visions in the minds of entrepreneurs. In the early stage, there are various such visions competing with each other. As the industry matures, the list of alternative designs is narrowed down, until a dominant one is arrived upon, to the exclusion of others (27). The dominant design will then be improved upon with use and made increasingly dominant through learning, economies of scale, and network effects. When studying technological trajectories, it is therefore important to examine the visions held by the involved actors, how they were formed, and how they shaped the outcome.

**Proposition 2: Uncertainty is overcome through cooperation**

For new entrepreneurs, there is no history of income statements for financiers to evaluate or existing assets to be pledged as collateral. There is only an intangible idea, which can only be judged on the basis of expected future profitability. Financiers who determine which projects to fund must do so, on the basis of detailed knowledge attained from, and about, the entrepreneur. This makes financing an inherently social process, “embedded in relations of a strikingly personal sort” [(28), p. 137]. Even in the most mundane forms of banking, Schumpeter [(14), pp. 116–117] noted,

The banker must not only know what the transaction in which he is asked to finance and how it is likely to turn out, but he must also know the customer, his business, and even his private habits, and get, by frequently ‘talking things over him’, a clear picture of the situation. But if banks, whether technically so called or not, finance innovation, all this becomes immeasurably more important.

To overcome uncertainty, the entrepreneur and financier need to collaborate closely, sharing the entrepreneur’s knowledge of production with the financier’s knowledge of markets. Because there is no objective metric to evaluate whether an innovation will succeed and the loan will be repaid, creditworthiness is “socially constructed” in the interactions between them [(29), p. 251].

Entrepreneurs’ ability to attain finance is largely determined by their network position. Ideally, it combines close ties that transmit the trust needed to maintain a credit line with ties to more distant connections that provide access to more remote information and market opportunities (30). Venture capitalists, who specialize in early-stage funding, need to be “rich in relationships even more than cash” (31). They operate by bridging “structural holes” in networks between entrepreneurs and large institutional investors (32, 33). Entrepreneurs seeking to construct innovative enterprises do so by harnessing the power of their networks to gather resources, discover opportunities, and gain legitimacy (27).

Although Schumpeter emphasized the role of the financial system as the handmaiden of creative destruction, he probably overestimated its role in funding new enterprises, which was uncommon even in his day (34). Most new ventures are financed by the entrepreneurs themselves or by money from family and friends (35). Early-stage finance often has “affective and charitable dimensions” [(36), p. 1688]. As Janeway argues, new technologies need support of a non-economic nature (20). The importance of cooperation to reduce uncertainty makes it important to pay attention to the concrete relations between entrepreneurs and financiers when studying the emergence of new industries.

**Proposition 3: Investment decisions have signaling effects**

Investment decisions are observed by actors other than the directly involved parties. If one financier grants a loan to an entrepreneur, it sets off a “sociological multiplier” that signals to other financiers that the venture is a sound investment [(37), p. 55]. Conversely, if one financier rejects an investment, it signals to others that it might be wise to do the same. This effect makes it important to study how investment decisions affect other parties through signaling.

**Proposition 4: Financial flows are shaped by power configurations between incumbent and challenger firms**

New entrepreneurs face the entrenched power of established firms (38). Incumbents seek to stabilize their position by integrating upstream or

downstream, diversifying into new lines of business, or seeking protection from the state. Challengers have to operate within the constraints set up by incumbents until they gather enough strength to dislodge them. Power asymmetries between incumbents and challengers are observed by financiers and shape their lending decisions. Market power is considered in financial evaluations of firms, allowing them to borrow on better terms than challengers (8). O’Sullivan [(39), p. 6] suggests that “we could ask whether incumbent firms dominate because they are more innovative or because entrants are too financially constrained to compete with them.” It is therefore important to examine how an industry was shaped by dynamics between incumbents and challengers.

**Proposition 5: Infant industries need protection**

Uncertainty and market power are hostile forces from which infant industries need protection until they mature. Schumpeter (1) argued that these could be provided by the monopoly power of large corporations, which allows them to cross-subsidize new product lines with their existing ones. Because firms rarely innovate in ways that would undermine their existing capabilities, the protected spaces for radical new low-carbon technologies would likely have to be provided by the state (40). As Kenney and Hargadon (41) demonstrate, private venture capital is not a viable model for most low-carbon technologies, which are capital-intensive and in direct competition with existing alternatives. Therefore, analyzing industry emergence makes it necessary to find out the extent to which immature technologies allowed protected spaces to mature.

**Proposition 6: Finance and production have different logics, driving them apart**

Fruitful cooperation between entrepreneurs and financiers is not guaranteed because they have different objectives. The goal of the entrepreneur is to expand production, and money is a means to this end. The goal of the financier is to make money, and production is one, but not the only, means to this end. If the financier could, he would rather skip the production phase altogether and turn money directly into more money. As Keynes observed, if there is easy money to be made by speculating on the future price of financial assets, capitalists will avoid investing in capital assets (8). Because financial firms are profit-driven actors just like all others, Minsky recognized that financial innovators will inevitably find ways of making a profit without having to engage in production. Others will follow their lead, eventually raising pressure on the state to legitimate financial innovations and give new financial instruments parity with state currency in the interest of maintaining financial stability.

The tension between the entrepreneurial and financial component of innovation can be resolved because both have a mutual interest in assuring that the loan will be repaid. However, circumstances determine whether the financier will want this to occur through the continued operations of entrepreneur’s enterprise or by having it liquidated. Following Carlota Perez, the entrepreneur can be seen as a representation of “production capital,” which is tied down in equipment, personnel, knowledge, and routines, whereas the financier represents “financial capital,” which is free to move [(42), p. 6].

Production capital is the agent for the accumulation of wealth making capacity; its natural horizon is long-term and it remains tied to its expertise. Financial capital is the agent for reallocating wealth in order to constantly maximize short-term returns. Production capital is therefore path-dependent while financial capital is fundamentally footloose and flexible.



While production capital is oriented toward expanding production, financial capital is oriented toward the moment when production is concluded and output is converted into money. Financiers and entrepreneurs can thus be defined as “the embodiment of two different moments in the circuit of capital” (43).

Finance has a disciplining effect on production capital, compelling it to increase efficiency, reduce costs, and provide products that customers want. However, it may impede the ability to develop entirely new products for markets that do not exist, which is an inefficient process of trial and error. Financial capital may aid creative destruction by redeploying resources from old to new industries. However, it may lack the patient capital to sustain them. The outcome is an empirical issue that varies between times and places, making it important to be attuned to historical and institutional analysis. Just like Schumpeter, Minsky saw capitalism as a system evolving through time, taking different forms under different institutional regimes. After financial speculation caused the Great Depression, finance was reined in during the managerial era, which, in turn, was followed by the era of money manager capitalism, in which finance again was allowed to break free (16). Given the differing logics of finance and production, it is important to ask how firms maintain “financial commitment.”

#### **Proposition 7: The balance of power between financial and production capital affects firm strategy**

In small firms, strategy can be set by the founder because ownership and control are vested in the same person. As the firm grows, these issues can become contested. Founders who want to leave their creations intact when they retire can make a profitable exit by selling shares in the enterprise on the stock market and leave it in the hands of the manager. Buyers of the stock become owners of financial claims on the enterprise but do not necessarily exercise control over the enterprise. In this case, financial control over production is diminished. When firms pay down debt and rely on retained earnings, the balance of power shifts from financial to production capital. The separation of ownership and control can lead the balance of power to shift in favor of productive capital, as was the case during the managerial era (44). After the Second World War, Minsky argued, deficit spending by the American government allowed corporate profits to rise to the level where corporations did not have to rely on external finance (16). This gave them managerial autonomy, allowing them to focus on long-term technological development. Although financial evaluations are based on publically available information, investments can be made out of retained earnings on the basis of specific knowledge of the firm’s capabilities that are only available to the firm itself. Hence, by relying on retained earnings, firms can free themselves of financial control and separate innovation from the incompatible logic that animates financial markets. This dimension of strategic control is essential to innovation (45).

The development led Keynes to perceive a tendency for “the big enterprise to socialize itself” and have it run in the interest of managers and employees instead of shareholders (46). Ultimately, this would lead to the “euthanasia of the rentier.” A side effect, according to Minsky, was that corporate organization descended into bureaucratization. Although government spending supported profits, only a small part of it went to technological development; the rest was used to underwrite consumption through welfare programs and military spending. Separation of ownership and control can lead to concern about excessive autonomy of managers to pursue growth strategies

that do not necessarily make economic sense or only do so on a long-time horizon (47, 48).

The function of finance, it may be argued, is to keep this from happening (43). During the 1980s “shareholder revolution,” financiers reasserted control. Thus, it ended the “independence of corporations from the money and financial markets that characterized the managerial era,” as Minsky argued (16). Instead, a new era of “money manager capitalism” came, in which the “main purpose of those who controlled corporations was no longer upon making profits from production and trade but rather to assure that the liabilities of the corporations were fully priced in the financial market, to give value to stockholders,” leaving “little in the way of internal finance left for the capital development of the economy.” Proponents of shareholder value argued that profits should not be reinvested but that managers should “disgorge the cash” so that other investors can find better use for them [(49), p. 323]. Since then, corporations have, to an increasing extent, become “managed by the markets” (50). The need to satisfy shareholders by meeting quarterly requirements for earnings per share has led managers to engage in financial engineering, such as stock buybacks, rather than investing in long-term innovation. Companies that manage to invest heavily in long-term innovation tend to be insulated from shareholder pressure through special classes of stock that keep founders in control [(51), p. 12].

Financial control is not necessarily exerted from outside the firm but can be implemented by financially oriented managers from the inside. Neil Fligstein has documented how this process began more than a decade before the shareholder revolution, during the merger wave of the late 1960s when corporations began expanding into unrelated businesses, turning themselves into financial conglomerates and managing their divisions like financial assets in a portfolio of stocks (52). A firm dominated by the agents of production capital tends to take a technology-based, internal diversification strategy, gradually expanding into new areas bordering their existing capabilities. A firm dominated by financial capital will be governed as a portfolio of assets, buying and selling divisions like shares on the stock market. Song [(53), p. 380] distinguishes between internal and external diversifiers in the following way:

Internal diversifiers generally exploit any synergies between current business lines and newly added business lines. External diversifiers decentralize operational functions to the operating divisions and concentrate mainly financial and legal control at top-level corporate headquarters.

External diversification can undermine the organizational coherence of the firm and move strategic control from actors that are knowledgeable about production to central headquarters governing through financial metrics. Innovation can be defined as an information creation process that proceeds through a process of small but cumulatively important contributions from those who are technologically knowledgeable (54). Christensen *et al.* (55) argue that financial control is an “innovation killer” because the richness of tacit knowledge is lost when it is transformed into simple numbers. Financial calculations are incapable of evaluating future technology and therefore invariably overestimate the life expectancy of existing technologies. The significance of power struggles between production capital and financial capital, which shape corporate governance, makes it important to focus on the issue of how actors who are knowledgeable about production processes maintain strategic control.

### Proposition 8: The relation between finance and production affects the relation between management and labor

Schumpeterian theory is mainly concerned with the tension within the capitalist class between the entrepreneur and the financier. Innovation is also shaped by the tension between capital as a whole and labor. Production and finance capital both belong to the capitalist class. Their collective goal vis-à-vis workers is to extract as much effort as possible for the least cost. Conversely, workers can be viewed to have the opposite goal, to exert as little effort as possible for as much pay as possible. However, the effort-minimizing worker may predominantly apply to alienated labor. Innovation would not be possible if human beings did not have an inherent will to create, an activity that is rewarding in its own right. The task of the innovative enterprise is to harness this drive. It can be done by sharing productivity gains with workers, giving them long-term careers and the ability to advance within the corporate hierarchy. William Lazonick refers to this solution as organizational integration (45).

Most innovation is incremental, consisting of minor but cumulatively major improvements to processes and products. Workers, who have local, tacit knowledge to upgrade the work process and equipment, are potentially major contributors to the process. When they are barred from participating, or when their tasks are narrowly defined and low-skilled, their incentives and abilities to improve the work process are diminished [(56), part 1]. Production capital and labor share the same preference for stability and long-term commitment. By freeing the firm from shareholder control, it may allow to orient itself to maximize benefits for employees, depending on institutional arrangements. When studying innovation, it is therefore important to examine to what extent firms achieve organizational integration.

### Proposition 9: Tensions are resolved with national institutional arrangements

Innovation depends on the fruitful integration of the three nodes of financial capital, production capital, and labor. Their interrelation is regulated by different institutional arrangements in different countries. Finance and production are not naturally connected; it takes conscious institutional bridging to achieve that, often occurring during extraordinary political events such as economic depression or war. Path dependency then tends to reinforce them.

As Roy (57) points out, finance and manufacturing in the United States had different historical origins and remained separated until they were joined together by the Civil War, laying the foundation for the corporate system of today. In Japan, the Asia-Pacific War had a similar effect, creating the close-knit nexus between industrial firms and banks of the postwar era (58). Corporate ownership was separated from control in both countries after the Great Depression, freeing the agents of productive capital from the constraints of financial capital (44). However, the tension reemerged forcefully in the United States, particularly with the “shareholder revolution” of the 1980s (59).

Labor unrest shook both countries in the wake of the Second World War but was resolved differently. In Japan, workers’ interests were aligned with management through vertical enterprise unions and lifetime employment. In the United States, horizontal labor unions remained strong enough to secure a truce with management, but blue collar workers remained segmented from management, not integrated with it, as in Japan.

Financialization is caused by nothing more than the removal of political constraints on finance. Krippner (60) documents how this

process, called depoliticization, has unfolded over the past decades in the United States. Depoliticization was a solution to the political problem of overt redistribution between interest groups. By deregulating finance and letting markets decide where finance should flow, politicians freed themselves from the responsibility of choice. Decision-making was moved from the realm of politics, where policy makers bear responsibility, to the realm of impersonal decision-making, either through technocratic control or to market forces.

This kind of institutional change has a profound effect on the financial structures that determine industrial change. The comparative study must therefore be attuned to the way in which the industry’s development is shaped by national institutional arrangements in the two countries. The following section will trace the evolution of the American PV industry from 1970 to 1989, framed by a comparison with the industry in Japan.

## RESULTS

After the 1973 oil crisis, American policy makers and firms made serious efforts to develop a viable solar PV industry. Despite optimistic projections and initial global dominance, the American industry did not take off. Japanese firms began making inroads in the early 1980s; by 2005, they had captured almost half of the global market, whereas the American share had declined to 9% (9). The industry’s center of gravity has since then moved toward China and Taiwan (61).

The disappointing performance of the American solar energy industry in the 1980s could be seen as the result of falling energy prices or flawed government policy, particularly the cuts under President Reagan (62). As this article emphasizes, however, the American solar strategy had underlying weaknesses to begin with. Solar cells were first given a protected space to develop in NASA’s space program, where they were used to power satellites (63). The subsequent development of the terrestrial American PV industry can be divided into three overlapping phases. First, a handful of small entrepreneurial firms pioneered the technology. Then, as the 1970s progressed, most of them were purchased by large conglomerates in the oil and electronics industries. Finally, in the 1980s, the conglomerates were broken up and their solar divisions were dismantled or sold off to foreign firms. There were large differences in how the original entrepreneurs and the large conglomerates viewed the future of the industry.

### Two visions

In the early 1970s, when the American solar energy industry did not yet exist, there were two competing visions of where it should head. One camp consisted of a small number of entrepreneurs who had been involved in producing solar cells for the space program or pioneered their application on Earth. They envisioned an industry of small-scale energy production off the grid [(63), p. 57; (64)]. Solar energy was too expensive to compete with conventional sources but had the advantage of being usable in remote locations or at sea. The pioneers saw a reasonably large potential in selling solar panels for these applications as roadside emergency phones, signaling systems for train crossings, electric fences, mountain-top communication centers, African villages, navigational aids, and consumer electronics. These markets could be served by small firms, without much investment in research or large production facilities. Profits from these sales could then be plowed back into technical improvements, enabling a further and gradual expansion of the market to less-remote locations until the technology was viable for widespread use. Modest policy

measures, such as mandating solar-powered lights at remote train crossings, were considered more helpful to spur the industry than lavish research grants [(63), p. 78]. The pioneers were later joined by a grassroots movement of Jeffersonian environmentalists who viewed decentralized energy as a means to escape the centralized power of large corporations and the state.

The other camp consisted of the energy policy bureaucracy and closely affiliated large manufacturing and energy corporations along with utilities (65). This camp was wedded to the idea of utility-scale PV generation, competing directly with conventional sources of energy. Official estimates held that this would become a reality sometime by the mid to late 1980s. Proponents of this view favored a massive increase in research and development to improve the efficiency of solar cells in the laboratory until they could compete with centralized energy production. A rapid move toward large-scale mass production was considered necessary to bring down costs. Both activities were capital-intensive, which meant that they needed to be conducted by large corporations. This preference had both ideal and material causes. The U.S. Energy Research and Development Agency that was responsible for developing PV was made up mostly of members from the recently disbanded U.S. Atomic Energy Commission. Their views were shaped by the experience of nuclear energy, a technology where large-scale and centralized energy production was the norm. Large manufacturing corporations also had a natural preference for large scale and centralization, and the research and production subsidies it would bring. In addition, naturally, utilities did not want decentralized energy producers as competitors.

Unsurprisingly, the large-scale vision prevailed. Apart from a brief period during the Carter administration when environmentalists were publically prominent, official policy overwhelmingly favored large corporations, granting them subsidies, tax breaks, and research assistance that helped them cement their position (66, 67). The orientation toward large corporations stood in stark contrast to state policy to promote semiconductors two decades earlier, which had a competition-enhancing orientation favoring small entrepreneurial firms (68, 69). The fact that American policy toward PV greatly favored large corporations would not necessarily have been a problem because large corporations also controlled the policy process in Japan (70). However, Japanese corporations, and hence policy makers, were oriented toward near-term markets instead of the future utility market [(71), p. 63]. As the study will emphasize, the main differences between the American and the Japanese trajectories reflected differences in industrial and corporate organization.

### Phase 1: Struggling entrepreneurs

The terrestrial American solar PV industry was founded by a handful of entrepreneurs. Their main difficulty was finding willing investors who could provide financial commitment. They managed to gather enough money from family and friends and sometimes more distant investors to launch their enterprises [(64), p. 20; (72), pp. 69; (76)], but they soon found it difficult to attain the needed funds to expand.

The first American PV firm to focus on the terrestrial market was Solar Power Corporation (SPC), founded in 1973 by Elliot Berman. He originally took his idea to a number of venture capitalists, but they “weren’t very venturesome” and declined the offer [(63), p. 53]. Instead, he turned to the oil company Exxon, which made SPC a subsidiary after Berman had convinced executives that solar panels were cost-effective for offshore oil platform lighting, pipeline corrosion protection, and surveying equipment. Others took notice and the oil in-

dustry soon became one of the most important markets for solar cells [(63), p. 66]. However, the involvement of oil companies would prove a mixed blessing.

The second firm to emerge was Solarex, also founded in 1973 by Hungarian immigrants Joseph Lindmayer and Peter Varadi. They did not have any luck courting venture capitalists either, visiting 20 of them without success, and developing “allergic reactions if somebody mentioned the word ‘venture capitalist’” in the process [(64), pp. 19, 192]. Bill Yerkes, who founded the third major PV firm Solar Technology International (STI) in 1975, visited an estimated 75 venture capital firms [(73), p. 44] before selling his firm to the oil company Arco 2 years later.

These three firms—SPC, STI, and Solarex—dominated the industry, holding around 80% of the American market into the 1980s (74). If they had trouble securing venture capital, less-prominent firms had no greater luck. Robert Willis who founded Solenergy was turned down by 10 venture capitalists, reporting that they were not interested in risky ventures but in established but fast-growing concerns [(75), p. 13]. Paul Maycock, who managed the U.S. Department of Energy’s PV program, assisted several small firms in their efforts to raise venture capital but reported that he did not manage to raise “a penny.” He cited the fact that “private sector risk capital wants to have return in the next 2 to 3 years” and that “[t]hose things that are 3 or 4 years out are very difficult to get funded” [(76), pp. 5, 18].

The failure to secure venture capital backing could be attributed to the fact that the stock market was not particularly interested in funding new firms during this time. Between 1970 and 1982, it was only reasonable to open initial public offerings for new companies during “six to eight quarters out of more than fifty” [(31), pp. 437–438]. The failure could also be viewed as an example of a network failure, as what Schrank and Whitford (77) call “network stillbirth.” Venture capital firms that were oriented toward high technology invested mainly in products that they were already familiar with (26). They made up a tight-knit group that tended to co-invest, particularly when making risky investments. If one firm did not choose to invest in a company, neither would others. Being excluded from this network meant that venture capital would not be available.

Bank loans were not a viable option for most entrepreneurs either. Smaller firms, such as Solenergy, found that banks were “were completely unfamiliar with photovoltaic technology, and were unwilling to spend the time necessary to understand its production and application” [(75), p. 13]. Equity funding was out of the question for all but a few firms with established parent companies or proven success in other industries. In 1978, Solarex was the largest terrestrial PV producer in the world but could not become listed on the stock market [(64), p. 193]. Without a close working relationship with entrepreneurs, investors could not assess the technology. As one representative of the investment community noted in 1979,

There is not at the present time a continuous dissemination of accurate information to bankers, underwriters, stock brokers, and insurance companies concerning the current state and expected development of photovoltaic technology, markets and industrial segment structure. If somebody in my community wants that information, they must go search it out [(78), p. 15].

Financial constraints made small firms struggle to survive even at the height of government support for the industry during the Carter years. The problem was outlined in a 1979 MIT report [(75), p. 1]:

Capital availability is not a problem in a well-functioning market. However, the market for photovoltaic cells is immature; in fact, the market for grid-connected photovoltaic applications... does not yet exist. Therefore, the capital markets cannot easily evaluate the credit-worthiness, the economic attractiveness of the variety of photovoltaic production processes, research programs, or end-use applications currently being developed. Only when photovoltaic technologies converge to a roughly standardized set of mass production methods and consumer applications will private capital markets perform their job of allocating financial resources to the photovoltaic industry.

The U.S. Department of Energy appears to have been unaware of the problem. In language reminiscent of the “efficient market hypothesis,” the agency describes capital markets as “among the more ‘perfect’ markets in existence” [(78), p. 65].

Solarex was an exception. It was the only independent firm that managed to bridge the financing gap without ceding control to an oil company. It did so in several ways—first, by attracting a sympathetic angel investor who explicitly likened his investment to a “charitable donation” [(64), p. 20]. This, in turn, convinced the First American Bank of Maryland to grant the firm a credit line. Solarex also formed a joint venture with French firm France Photon, giving it access to African markets, and obtained equity funding from Holec, a Dutch electrical company, and Leroy-Somer, a French electric power-generating company. The oil company Amoco also invested in the firm, without taking control over it, which gave Solarex’s bank the confidence to expand its credit line. When the bank finally withdrew their credit line in 1983, Varadi and Lindmayer saw no other option but to cede strategic control of the firm and let it become a wholly owned subsidiary of Amoco [(72), p. 116].

## Phase 2: Conglomerates take over

Beyond a lack of information, small firms had difficulties securing finance because investors knew that huge conglomerates were in competition with them [(72), p. 80]. In other words, the opportunities of challengers were heavily circumscribed by incumbents. Banks wondered “how a small business could compete with subsidiaries of Mobil, Exxon, Shell, Arco, Motorola, and Texas Instruments” [(75), p. 13]. Small firms that did acquire finance could mainly cater to small specialty markets. For example, the founder of Solec consciously avoided investing in research, expensive materials, and direct competition with oil companies [(79), p. 30]. The American PV industry became bifurcated, consisting of one segment that focused only on long-term research and another on manufacturing [(69), pp. 122–124]. Only independent firms backed by oil money could do both. The divided industry could not put up a united front in their efforts to influence energy policy. Strapped for cash, several small PV firms survived by selling their technology to Japanese competitors [(74); (76), p. 12].

Capital constraints for small firms were so great that, at the end of the 1970s, it was considered probable that “the mass-production photovoltaic industry will consist entirely of wholly-owned subsidiaries of (large) conglomerates” [(75), p. 28]. Paul Maycock, who ran the U.S. Department of Energy’s PV program, assumed in 1980 that the PV market would resemble the oligopolistic auto industry rather than the competitive electronics industry: “In the end,” he predicted, “we are going to have four companies, as in the automobile industry” (80).

The Federal Reserve appears to have exacerbated the problem with its monetarist experiment of extraordinary high interest rates in 1979 to 1982. Beyond raising the price of credit, the policy harmed the PV industry by attracting foreign capital flows that pushed up the value of the dollar, hurting exports, which accounted for 70% of PV sales at the time [(76), p. 53; (81), p. 12].

Most independent entrepreneurs were compelled to sell their firms to large conglomerates, worsening the situation for the few independents that remained. Conglomerates were reportedly “cross-subsidizing below-profit production in order to secure a market share in the longer run” [(82), p. 24]. By handing over operations to conglomerates, entrepreneurs ceded strategic control over their enterprises. Production decisions would, from then on, be made in central headquarters, far away from the shop floor, not on the basis of deep knowledge of manufacturing but on the quantitative measure of return on investment [(75), pp. 15–18].

When large corporations took over, so did the large-scale vision they favored. Elliot Berman’s small-scale vision for SPC clashed with Exxon’s, and when he left in 1975, the firm lost its leadership in building niche markets [(64), pp. 110, 129]. Solarex had catered to niche markets during the 1970s, but after it became a subsidiary of Amoco, the focus began shifting more toward the “big picture” goal of reaching “grid parity” with other forms of conventional energy production [(64), p. 187]. For oil majors to make a satisfactory return on their investment, they had to break through into the grid-connected utility electricity market. As one observer of Arco put it, “building solar-powered water pumps for Egyptian farmers was not Arco’s idea of a big market” (74).

The American PV industry was greatly affected by changes in corporate structure and strategy from the late 1960s to the 1980s. In the late 1960s, a new clique of financially oriented managers came to dominate American corporate governance (52). Their conception of control was to manage the corporation like an investment portfolio, buying and selling firms in other lines of business. As Espeland and Hirsch [(83), p. 78] describe them, “[t]hey were more financiers than managers, concerned with deal-making more than with the day-to-day operations of the companies they bought.” Most American corporations evolved into financial conglomerates, managing their subsidiaries from central headquarters with an arm’s length approach. Financial conglomerates tended to be “quite ‘thin’ at the top,” their administrative structure “fashioned simply to watch over and allocate capital among a portfolio of businesses, there being no central research and development or central staff-coordinating offices” [(84), p. 23]. Tacit information about production was transposed to formal information as decision-making moved from the shop floor to managers relying on quantitative measures such as return on investment (85). As conglomerates expanded into ever more diverse product lines, organizational integration eroded and strategic control moved out of the hands of personnel with intimate knowledge about production into the hands of financial managers in central headquarters.

Bill Yerkes of STI described his firm’s parent company Arco as a “bumbling behemoth” with no knowledge of PV or even of manufacturing in general [(72), pp. 80–84]. Against Yerkes’s protests, the company abandoned research in cadmium telluride and switched to amorphous silicon, resulting in a defective product that had to be withdrawn from the market twice. Despite its \$200 million investment, Arco did not manage to turn a profit. Anticipating an expiration of tax credits, Arco rushed to construct the world’s largest PV plant without properly vetting the technology. Completed in 1985, it was never used.



Similar problems plagued other conglomerates. RCA had pioneered thin-film solar technology but lacked the managerial resources to commercialize it and sold it instead to competing Japanese firms [(86), pp. 156–158]. It soon gave them their competitive edge in the market for solar calculators. Although conglomerates provided the PV industry with financial commitment through cross-subsidization, they lacked the other two social conditions of the innovative enterprise: strategic control and organizational integration. In the 1980s, financial commitment would erode as well.

### Phase 3: Conglomerates are dismantled

While the American financial conglomerates of the 1970s were inept at developing PV, the situation worsened even more during the 1980s when the conglomerates were taken apart. The American corporation experienced a deep crisis in the 1970s to a large extent because of Japanese competition. In the 1980s, the strategy of unrelated diversification was delegitimized, and a new conception of control was instituted, continuing the trend toward increasing financialization. The rise of shareholder value and a concomitant restructuring of the American corporate landscape made corporations reverse their previous move toward diversification (87, 88). Cross-subsidization of diverse product lines was discontinued (89), causing a loss of financial commitment to PV technology. Deregulation and new debt instruments made it possible for corporate raiders to launch hostile takeovers or “greenmail” companies for cash. The already vulnerable PV industry became a victim of the upheaval. In the 1980s, “[s]olar companies in the United States became pawns in the market for corporate control” [(79), p. 36].

General Electric (GE) epitomized the new corporate philosophy, leading the way in shareholder value maximization under its new chief executive officer (CEO) Jack Welch. Shortly before he took over in April 1981, GE had made plans to expand its solar operation (90). The company had built one plant in 1980 and was planning to build another one in 1984. It also offered to buy the small firm Solec. When Welch took over, he trimmed the organization, refocused the firm, and launched hostile takeovers against other companies (91). He declared that GE was exiting all industries where it was not number one or number two, and solar energy was not one of them.

One of the victims of GE's takeover bids was RCA. The company's flawed diversification strategy in the 1970s had left it deep in debt, and the early 1980s saw the company desperately struggling to cut costs while “fending off a swarm of corporate raiders” (92). A new CEO refocused the firm on its core competency, selling off its solar division to Solarex, which subsequently became a subsidiary of Amoco (93).

The oil industry was particularly hard-hit by corporate raiders, who forced firms to restructure, shed unrelated businesses, and focus on the core competency (94, 95). Exxon had grown to immense size during the oil boom. Once oil prices declined, shareholders put pressure on the company to shed assets (96). The company sold its solar division, sending a signal to Wall Street that solar was “in the dog house” (97). Philips Petroleum had formed joint ventures with two solar firms in the early 1980s: AeroChem and Acurex. In 1985, corporate raiders set their sights on the firm, compelling it to go deep into debt to buy back stock. To repay the debt, the company sold assets, among them its solar positions. A company representative told the press that it could not afford the “luxury” of investing in alternative energy in the current environment (98).

Standard Oil of Ohio (Sohio) partnered with the innovative PV firm Energy Conversion Devices (ECD) to develop amorphous silicon technology (99). In the mid-1980s, the parent company British Petro-

leum grew dissatisfied with the firm, whose unprofitable exploration and diversification strategies depressed the stock price. A new CEO was sent in to restructure the firm to maximize shareholder value (100). Shortly thereafter, the firm sold off its stake in ECD, which instead partnered with Japanese firm Canon (101, 102).

The founders of Solarex also lost strategic control of their operation. The parent company Amoco had initially allowed them autonomy to continue to cater to small markets, but this changed in the mid-1980s. A new financially oriented management shifted focus and “eliminated everything that was not related to the ‘core business,’” including “the entire consumer business, catalogs, and stores” [(64), p. 187]. In the 1990s, the division survived through fraudulent tactics used by its partner firm Enron before it was merged into BP Solar (103).

Arco also experienced a shift in direction in the mid-1980s, when shareholder-oriented management was brought in to cut costs (93). Fearing a hostile takeover, the company spent billions of dollars buying back its own shares and divested from nonstrategic assets. In line with Wall Street practice, it refocused the company on its core competence, carbohydrates (104). Arco solar, which was the biggest PV firm in the world at the time, was sold to the German company Siemens. Energy analyst Philip K. Verleger Jr. at Charles River Associates explained the move by saying that American firms were “too tied up in short-term profits” to make the commitment necessary to make PV economically viable. As the *New York Times* summarized his argument, “[a] publically held company that invested heavily in solar technology would probably become the target of a corporate raider who would argue that shareholders' money would get quicker profits elsewhere” (105).

### Comparison with Japan

In 1978, American firms held 95% of the global market share; in 1984, it had declined to 55% [(106), p. 69]. The shift was mainly caused by Japanese competitors, who were integrating solar cells with consumer electronics such as calculators and watches. Building on these capabilities, Japanese firms later lobbied the state to provide residential subsidies, massively increasing the size of the industry (107). By the early 2000s, almost half of the world's solar panels were manufactured by Japanese firms.

One of the most consequential developments behind the declining competitiveness of American PV took place outside the PV industry. In the 1970s, Japanese firms made inroads into industries related to PV, conquering almost half of the global semiconductor market and wiping out large parts of the American consumer electronics industry (108). These firms viewed PV as a complementary investment to their existing capabilities, where they could plow some of their retained earnings (107).

Japanese electronics firms' main competitive advantage was financial commitment, secured through close ties with banks (109, 110). The Japanese postwar financial system was specifically designed to encourage investment in productive instead of speculative activity, partly inspired by the economic theory of Joseph Schumpeter (111). Banks provided firms with “dedicated capital” available for “long periods of time, without regard to short-term returns” [(112), p. 250]. Although Japanese banks turned highly speculative in the 1980s, corporate finance was largely insulated from these pressures by blocs of stable shareholders (113). Perhaps even more important than access to reliable credit was retained earnings and Japanese managers' ability to exercise strategic control over them without regarding to shareholders' interests. Managers were freed from “the restrictions of short-term

perspectives” to set “long-term goals” [(114), p. 175]. Because of the institutional arrangement of cross-shareholding, in which firms held each other’s shares for the long term, Japan did not experience a “shareholder revolution” as the United States. Instead of managers being compelled to act like shareholders, institutional arrangements in Japan compelled shareholders to act like managers [(115), p. 227]. Crucially, Japanese PV producers were not subject to the “market for corporate control.” Beyond protecting against hostile takeovers, cross-shareholding meant that Japanese managers were “under less compulsion to sustain high quarterly profits than their U.S. counterparts, and therefore freer to focus on long-term expansion of market share” [(116), p. 44].

Last, and partly related to these events, a key strength of Japanese firms was the organizational integration of workers in the innovation process. American firms were segmented between white collar and blue collar workers [(56), part 1]. In Japan, (male) blue collar workers were integrated into the innovation process. Iwata (114) argues that the elimination of shareholder control after the Asia-Pacific War turned the Japanese enterprise into a “unified body of employees.” Lifetime employment turned the worker from “an external seller of his labor” to a “corporatist who shares the responsibilities of management” [(114), p. 176]. At Kyocera, one of the top Japanese PV producers, workers were organized in self-managing teams known as “amoebas.” According to Florida and Kenney [(117), pp. 158–159], this organization was a mechanism for “generating internal, self-imposed discipline, devolving manager responsibility to the shop floor, and motivating workers to work harder,” thereby “harnessing workers’ knowledge and collective problem-solving capabilities for the enterprise.”

In summary, Japanese institutional arrangements—bank financing, cross-shareholding, enterprise unions, and lifetime employment—aligned the interests of financial capital, production capital, and labor in a manner that allowed them to maintain the social conditions of innovation. Consequently, Japanese firms drove American competitors out of the electronics and PV markets. They also avoided the corporate upheaval that afflicted their American rivals—a restructuring that, to a large extent, was caused by Japanese competition in the first place.

## DISCUSSION

This case study has revealed how the tension between productive and financial capital obstructed the development of the American PV industry. The American industry was greatly affected by changes to corporate governance brought by the trend toward increased financial dominance in the 1970s and 1980s: first, through conglomeration, in which corporations became governed as a diversified portfolios of assets to be bought and sold like stocks, and second, through its subsequent reversal in the 1980s, when financial deregulation allowed corporate raiders to break up the conglomerates, changing corporate governance in the process. The initial involvement of large financial conglomerates was ambiguous because they provided needed financial support but steered the industry away from existing markets toward a large-scale utility market that never emerged. By focusing almost exclusively on creating a future market for centralized energy generation, American firms missed the opportunity to develop the small off-grid and consumer electronics markets that were already available. There was an alternative path that was not taken toward decentralized solar energy, which would not have to compete with conventional sources. We know this because that is how the industry developed in Japan, where solar cells were applied mainly for off-grid use and consumer

electronics, allowing the technology to mature gradually without much reliance on subsidies or record-level energy prices. This article demonstrates that the main reason this path was not taken in the United States was a disconnect between industry and finance.

The entrepreneurs who had the deepest knowledge of the technology and the markets where it would be cost-effective lacked connections to the financial sphere. Consequently, most of them succumbed to large financial conglomerates, which were inefficiently governed by arm’s length relations from central headquarters at first and by even more distant financial markets later. This made entry possible for Japanese firms, whose institutional and financial arrangements insulated them from financial constraints and destructive conflicts between shareholders and managers. The absence of financial control also allowed greater integration of workers in the innovation process.

The agents of productive and financial capital cooperated fruitfully in the Japanese PV industry but failed to do so in the United States. The failure represents an expression of an inherent tension between the entrepreneurial and financial components of innovation. Recognizing this tension is crucial to understand the challenge of industrial transformation required to avoid catastrophic climate change. It cannot be assumed that, by correcting market failure by putting a price on carbon, the financial system will adjust passively. Although a carbon tax would make low-carbon technology in general more competitive, there is no way of knowing which specific future technologies will succeed. The only sure thing is that most new technologies will fail. Innovation is always uncertain and wise to avoid if there are easier ways to make money off of speculation. Keynes noted that the ever-present tendency toward financialization calls for a substantial share of public investment. This is particularly true of extra-market goals, such as the mitigation of climate. Because, in Keynes’ theory, resources are almost never fully used, public investment does not compete with private investment. The importance of specific knowledge in financing decisions means that these public entities should have very specialized domains of operation. Perhaps, the recently expanded role of central banks in economic governance could play a role in developing low-carbon technology, a topic worthy of future investigation.

Industrial policy is necessary to guide the transition to a post-carbon future, but it works best when it allows decentralized credit creation for technological development by private entrepreneurs and financiers. This requires a financial system that promotes credit creation for productive rather than speculative activity. A political strategy to bring productive and financial capital together is needed. It is necessary to close off easy ways of making money off money, such as speculation and stock buybacks. This article has examined ways in which financialization impedes the development of low-carbon industries. It has not examined ways in which financialization may aid it. This interesting issue needs to be addressed in further studies.

## MATERIALS AND METHODS

This project used a historical-comparative case study approach, which allowed causation to be studied in historical time (118, 119). It focused on the relationship between entrepreneurs and financiers in small and large American solar firms between 1970 and 1989, contrasting the American solar industry with the situation in Japan. Japan was chosen as a reference because it has an economy of roughly half the size of the United States while managing to foster a PV industry with a global market share many times the American share (9). The method required a broad overview of developments in the wider institutional context

surrounding the firms under study. Because accounts differ, as they always do in social science, extensive referencing of second-hand sources was necessary.

The study of the PV industry deliberately utilized a variety of bibliographic sources, including business press articles, governmental reports, congressional hearings, academic articles and books, and biographical accounts by involved entrepreneurs. Searches for newspaper articles referencing solar energy or PV cells, as well as the names of the firms involved in the industry, were made in databases ProQuest and LexisNexis between the years 1970 and 1990, along with analysis of annual reports of the large corporations involved.

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