STOCK MARKET UNDERVALUATION OF RESOURCE REDEPLOYABILITY

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ABSTRACT

Resource undervaluation is the key premise of strategic factor market theory. When applied to corporate acquisitions, the premise conflicts with stock market efficiency. The conflict has not been resolved in empirical studies that either assumed or assertively denied target underpricing. This study establishes theoretically the stock market undervaluation of resources. While not considering the corporate acquisition process in its entirety, the study explains when stock markets undervalue firms, thus enabling excess returns to acquirers. The study focuses on a specific source of undervaluation, resource redeployability, the option for an evaluated firm to withdraw its resources from the existing business and switch them to a new business. The explanation is developed using a formal model based on established insights into the implications of ambiguity for valuation.

Keywords: strategic factor markets; resource redeployability; ambiguity; real options; valuation.

INTRODUCTION

A key insight of strategic factor market theory is that firms earn above-normal returns when they buy resources at prices below the true value of those resources in implementing product market strategies (Barney, 1986). Excess returns can be realized through (a) ‘luck’ (Barney, 1986) when a firm happens to buy underpriced resources; (b) ‘serendipity’ (Denrell, Fang, and Winter, 2003) when a firm discovers the true value of resources after trying them in new uses; or (c) ‘strategic factor market intelligence’ (Makadok and Barney, 2001) when a firm collects, filters, and interprets information about the resources before buying them. While these explanations differ in the extent of rationality involved in the discovery of strategic opportunities, they all rely on the pre-existence of *undervaluation* of resources.

The required undervaluation is most intriguing in corporate acquisitions, where firms buy stock in other firms that possess targeted resources. Thus, Barney (1986: 1232) asserts that ‘the market for companies is a strategic factor market.’ The view of the stock market as an outlet, where firms can obtain resources at a cost lower than they would otherwise incur, concurs with earlier discussions (Keynes, 1936: 151; Penrose, 1959: 160). Indeed, Lev (1983) and Trautwein (1990) reviewed merger motives and found stock market undervaluation of targets to be a key rationale for acquisitions. That rationale was implied in many empirical studies of target choice (De Bondt and Thompson, 1992; Yu, Umashankar, and Rao, 2016), bid premiums (Laamanen, 2007; Varaya, 1987), and acquirer returns (Carow, Heron, and Saxton, 2004).[1] However, there has also been a very compelling objection to the idea that stock market undervaluation of a firm can be detected by acquirers. In particular, proponents of efficiency of stock markets view them

[1] There has also been abundant evidence from interviews (Ravenscraft and Scherer, 1987: 9) and surveys (Mukherjee, Kiymaz, and Baker, 2004) of managers of bidding firms indicating that they do seek undervalued targets in corporate acquisitions.

as 'amazingly successful devices for reflecting new information rapidly' and eliminating any 'predictable patterns' of undervaluation (Malkiel, 2003: 60).[2] Despite that objection, research that appeals to strategic factor market theory has not theoretically defended undervaluation of a firm's resources in the stock market. In particular, formal models (Adegbesan, 2009; Makadok and Barney, 2001; Maritan and Florence, 2008) have been restricted to a game played by a few firms that engage directly in resource deployment and bargain over resource prices. Such models have assumed that bidding firms are either informed asymmetrically about targeted resources or vary in utility of deploying those resources; but those models have not captured the behavior of diffuse investors, distant from actual resource deployment yet jointly setting prices for resources in the stock market. Furthermore, empirical research has either uncritically embraced stock market efficiency, denying acquirer gains from the target underpricing (Anand and Singh, 2004; Capron and Shen, 2007; Seth, 1990), or assumed undervaluation instead of establishing it theoretically (Carow *et al*., 2004; Laamanen, 2007; Yu *et al*., 2016).[3] Hence, the stock market undervaluation, demanded by strategic factor market theory, remained a contested assumption.

This study attempts to theoretically establish stock market undervaluation of a firm's resources. While not intending to cover the corporate acquisition process in its entirety, the study explains when stock markets undervalue target firms, thus enabling excess returns to acquirers. The study focuses on a specific source of undervaluation, *resource redeployability*, the option for an evaluated firm to withdraw its resources from an existing business and switch them to a new business (Sakhartov and Folta, 2014). The focus on redeployability addresses the gap in research

[2] Skepticism about the ability of bidders to profit from the target underpricing was shared in strategy research (Porter, 1987: 33).

[3] On one hand, Anand and Singh (1997) used market returns to bidders as a measure of their performance. That proxy embraced market efficiency, which the study sought to support. Capron and Shen (2007) studied bidders' returns and assumed that capital markets are efficient. Seth (1990) studied value creation in acquisitions and refuted gains from target undervaluation. On the other hand, Carow *et al*. (2004) explored early-mover advantages for bidders and assumed that target firms are undervalued in the stock market. Laamanen (2007) assumed that targets, for which bid premiums are paid, are underpriced. Finally, Yu *et al*. (2016) implied that bidders seek targets priced below the cost the bidders would incur in creating the targeted resources internally.

about its value. On one hand, formal models of redeployability (Kogut and Kulatilaka, 1994; Sakhartov and Folta, 2014; 2015; Triantis and Hodder, 1990) implied equilibrium among market players who knew a probability distribution for the uncertainty involved and updated estimates for redeployability, instantly and accurately, upon the arrival of new information. That approach agreed with market efficiency, also embraced by empirical studies where stock market value was deemed to reflect the true value of redeployability (Anand and Singh, 1997; Montgomery and Wernerfelt, 1988). On the other hand, in some situations, the evaluators of redeployability cannot assess a probability distribution. When a new business has just emerged and the current business has not yet redeployed any resources to the new business, there are no data points to assess the probability distribution. That context, with missing data about a unique event, has been defined as *ambiguity* (Frisch and Baron, 1988), and has been proven to render *ambiguity aversion* (Ellsberg, 1961). Empirical research has shown that, in the face of ambiguity, ambiguity-averse investors do not efficiently process new information (Williams, 2015) and instead count on the worst-case scenario, thus underpricing the evaluated asset (Drechsler, 2013). Nevertheless, the option to redeploy resources begins objectively with inception of the new business, and reveals its true value in the stock market only when ambiguity is fully resolved.

Although this study focuses on redeployability, its appeal to the ambiguity due to the uniqueness of the evaluated strategy is related to several studies that have mentioned similar valuation challenges. For example, Barney (1988) suggested that a target firm’s stock price may not reflect the unique synergy with its acquirer. Similarly, Litov, Moreton, and Zenger (2012) highlighted the ‘uniqueness paradox.’ They claimed that, while firms enhance their true value by creating unique sets of businesses with complementary resources, that uniqueness can be discounted by the stock market. Finally, Zuckerman (1999) argued that a firm that cannot attract stock market analysts who specialize in its particular businesses is viewed as illegitimate by the stock market and therefore trades at a discount. That failure to attract specialized analysts was related to the uniqueness of the firm's identity, which Zuckerman (1999) exemplified by the combinations of businesses that took place in diversified firms. While those studies complement the present research, by providing additional reasons for undervaluation of resources in the stock market; this study is unique in identifying, rigorously and separately, true value and stock market valuation, thus formally deducing undervaluation as a function of resource properties.[4]

To separately identify true value and stock market valuation of redeployable resources, this study builds a formal model involving two parts. The first part uses the model of Sakhartov and Folta (2015), with the most comprehensive list of determinants of redeployability, to derive true resource value that would occur in the efficient market. The second part uses the same determinants, but it evaluates resources in the market, where investors face ambiguity about redeployability. By varying the degree of ambiguity, the second part of the model accommodates the likely evolution of the valuation context for redeployability: from the initial very high degree of ambiguity, which leads to a very high degree of undervaluation, to a full resolution of ambiguity, which enables efficient valuation. To find the stock market valuation of resources in the presence of ambiguity, the second part relies on the established 'maxmin' approach wherein ambiguity-averse investors count on the worst-case scenario for an ambiguous consideration (Gilboa and Schmeidler, 1989). The difference between the two valuations is the undervaluation.

The model has two key results. First, the stock market undervaluation of redeployability is derived as a function of its determinants and ambiguity. While the effect of ambiguity follows from ambiguity aversion; the study of how determinants of redeployability affect undervaluation,

[4] Although Maritan and Florence (2008: 229) speculated that redeployability is more susceptible to inefficient valuation than complementarity, the present theoretical study is agnostic about that comparison and leaves its resolution to empirical research.

both directly and *via* the interaction with ambiguity, produces novel results. The empirical operationalization, offered here and based on the established valuation models, is a reasonable alternative to the approaches that either ruled out or assumed stock market undervaluation. The operationalization can be used both in research on corporate acquisitions and by corporate managers seeking contexts where corporate acquisitions could be advantageous due to resource undervaluation. Second, the model detects the *redeployability paradox*: the same parameters that make redeployability more valuable objectively may also make it more undervalued in stock markets. Although it resembles the uniqueness paradox (Litov *et al*., 2012), which pertains to complementary combinations of businesses in diversified firms, the redeployability paradox applies to the option for any firm to redeploy its resources to a new business. The redeployability paradox was not part of empirical tests (Anand and Singh, 1997; Montgomery and Wernerfelt, 1988), which measured the true value of redeployability as the stock market valuation and did not seek an undervaluation. Moreover, the redeployability paradox is more subtle than the uniqueness paradox. While some determinants of redeployability simultaneously enhance true resource value and stock market undervaluation, the paradox is rejected with other determinants. The present study establishes conditions under which the redeployability paradox holds. Parameters used to formally derive such conditions and predict stock market undervaluation of redeployability are first introduced qualitatively in the next section.

REDEPLOYABILITY, AMBIGUITY, AND RESOURCE UNDERVALUATION

A model of stock market undervaluation of redeployability demands a list of predictors of its true value and of its stock market valuation. Those predictors are collected from two separate streams of research, on redeployability and on ambiguity, which are reviewed in turn below.

Research on resource redeployability

Redeployment of firms' own resources to new businesses has long been considered an important strategy. For example, Chandler (1962) and Penrose (1960) chronicled how E.I. du Pont de Nemours & Co. and The Hercules Powder Company, respectively, redeployed their resources from the declining explosives business following the end of World War I. Similarly, the former head of Bombardier Inc., Laurent Beaudoin, described redeployment of manufacturing plants and employees to subway cars after demand for snowmobiles had collapsed in 1973 (Baghai *et al.*, 1997). Helfat and Eisenhardt (2004) have theoretically justified such redeployments as enacting 'inter-temporal economies of scope.' How firms enhance value by redeploying their resources between industries has also been examined by multiple empirical studies (Anand, 2004; Anand and Singh, 1997; Lieberman, Lee, and Folta, 2016; Wu, 2013). Existing research has both identified determinants of redeployability and formalized its evaluation.

Determinants of resource redeployability

As Penrose (1959) argued, resource redeployment is induced by the return advantage of a new business over the original business, and is hampered by the redeployment cost between those businesses. Redeployment costs between businesses were captured inversely with relatedness, the similarity of their resource requirements making resources more-applicable to the new use (Anand and Singh, 1997; Montgomery and Wernerfelt, 1988; Wu, 2013). Inducements were measured as the current return advantage in a new business (Anand and Singh, 1997; Wu, 2013), as return volatility (Kogut and Kulatilaka, 1994), or as return correlation between businesses (Triantis and Hodder, 1990). Sakhartov and Folta (2015) explained that each of those proxies plays a unique role. Thus, correlation reduces inducements by making returns in two businesses converge, and decreasing the chances of a future return advantage in one of them. Volatility raises inducements by widening confidence bands for returns and expanding future advantages. The current return advantage enhances inducements by putting the band for returns in the new business above the band for the current business.

Evaluation of resource redeployability

A formal model of redeployability with the most complete list of its determinants was built by Sakhartov and Folta (2015). That study, like similar earlier models (Kogut and Kulatilaka, 1994; Sakhartov and Folta, 2014; Triantis and Hodder, 1990), used option pricing in complete markets (Cox and Ross, 1976; Harrison and Kreps, 1979), where each source of uncertainty matches a unique asset traded in the market (Björk, 2004). A change in that market is reflected in new asset prices and is learned instantly by market players. The resulting price for redeployability implies equilibrium among market players, who maximize expected utility. According to Savage (1954), market players assess expected utility based on subjective priors for future states of the market, which must be summarized with a probability distribution. The derived equilibrium option price represents true value of redeployability, the value that would occur in the efficient market.

Investor ambiguity about redeployability

Besides measurable uncertainty, with which market players can assess probabilities of future events, evaluators often confront ambiguity, with which data on future states of the nature are too imprecise to be represented with probabilities or matched to traded assets. [5] Ellsberg (1961: 660) argued that, with ambiguity, 'behavior violating the Savage axioms may commonly occur.' The issues of why ambiguity pertains to redeployability, and how it affects stock market valuation, are addressed based on existing conceptions of the origin and implications of ambiguity.

[5] The author thanks Jay Barney, who commented that ambiguity is different from Knightian uncertainty. Langolis and Cosgel (1993) carefully reviewed Knight (1921) and concluded that he had referred to the inability of evaluators to identify possible future states of the nature. In contrast, ambiguity occurs when evaluators know future states but not their probabilities.

Origin of ambiguity: uniqueness of redeployment event

Ambiguity denotes 'the subjective experience of missing information relevant to a prediction' (Frisch and Baron, 1988: 152). People face ambiguity 'where the sample for studying the event is small' (Einhorn and Hogarth, 1985). As Bernstein (1996: 302) wrote, people 'can calculate probabilities from real-life situations only when similar experiences have occurred often enough. But when events are unique ambiguity takes over.' Such uniqueness pertains to redeployment, the key event with which redeployability unveils its value. When a new business has just emerged and no redeployment has occurred from the original business to that new business, stock investors have no data with which to estimate a probability distribution for redeployability. Meanwhile, as long the new business exists, the mere option for redeployment of resources from the original business to the new business adds value, regardless of the actual redeployment. As Denrell *et al*. (2003: 981) described, that option represents an 'unactualized possible' that is real even before exercised but may not be accounted for in the market.[6]

While any determinant of redeployability may be ambiguous, sources of ambiguity can be ordered based on their associated level of uniqueness. First, ambiguity about returns in the original business is likely to be relatively low because investors can estimate the probability distribution from past returns of that business. Second, before redeployment occurs, investors can assess the probability distribution for returns in the new business based on its emerging record; although some ambiguity can remain when the record is short. Third, before redeployment, the costs of redeployment between the original and the new businesses are very ambiguous to investors because there is no available record on the outcomes of such redeployment. That ambiguity with regard to redeployment costs evolves from very high (when

[6] Unlike the current focus on the novelty of a particular redeployment, Denrell *et al.* (2003) emphasized the multiplicity of destinations for redeployment as a key obstacle for market efficiency, though both approaches appeal to ambiguity.

no redeployment has occurred yet) to dispensable (when numerous redeployments have occurred), contrary to the assumption in the extant valuations that such ambiguity is absent.

Implication of ambiguity: ambiguity aversion

The key behavioral implication of ambiguity is ambiguity aversion, with which people avoid betting on outcomes that have unknown probabilities. Such aversion was identified in the experiment by Ellsberg (1961), who allowed subjects to bet on picking a ball of a particular color from one of two urns, each with 100 balls. The subjects were told that the first urn included an unknown ratio of red and black balls, and that the second urn included exactly 50 red and 50 black balls. Given the option to win money for picking a ball of the color they had chosen before the trial, the subjects preferred to bet on the second urn. That result demonstrated the subjects' aversion to the ambiguity regarding the ratio of balls in the first urn, despite the fact that both urns offered the same chances for a successful bet. Several psychological reasons for ambiguity aversion have been suggested: (a) people consider unfavorable outcomes more likely (Yates and Zukowski, 1976); (b) people make choices they could justify to others (Ellsberg, 1963); (c) people make choices minimizing anxiety and regret (Ellsberg, 1963); and (d) people make errors that appear to be ambiguity aversion (Roberts, 1963). Of those reasons, the concern about the *ex post* evaluation by others received the strongest support (Curley, Yates, and Abrams, 1986). In that case, the decision-maker feels a responsibility to other people observing the choice and desires to appear competent.[7]

Ambiguity aversion observed among people in general has been confirmed specifically among stock market investors. For example, Antonioua, Harris, and Zhang (2015) have shown that ambiguity significantly reduces people's willingness to invest in stocks. Also, Anderson,

[7] For example, in providing the target price for a stock, market analysts are concerned about whether their forecast will match the actual realization of the stock's price and about the resulting estimate of their competence by market investors.

Ghysels, and Juergens (2009) studied empirically how stock prices depend on uncertainty and ambiguity. They found that investors demand higher returns when facing uncertainty or ambiguity, and that the effect is stronger for ambiguity. In addition, Jeong, King, and Park (2015) have confirmed that ambiguity makes investors demand a high premium for possible losses not characterized by a probability distribution. Ambiguity aversion was also isolated empirically from the efficient valuation with delayed information. In particular, Williams (2015) has found that stock investors, when pricing a stock, fully accounted for bad news in the firm's earning announcements but tended to disregard good news. That pattern contradicted the requirement of market efficiency that all news should be promptly and indiscriminately factored into the stock price. Finally, ambiguity aversion has been demonstrated to lead to a very specific valuation bias. Thus, Drechsler (2013) has demonstrated that, when investors face ambiguity, they hedge against it by pricing securities based on the worst-case scenario rather than on all possible outcomes weighted by their probabilities. That aversion results in the strongest possible downward bias.

Ambiguity aversion, diagnosed experimentally and revealed empirically, was formalized with the 'maxmin' expected utility of Gilboa and Schmeidler (1989) that amended the subjective expected utility of Savage (1954). That method, used to derive asset prices and investor behavior in the presence of ambiguity (Antonioua *et al*., 2015; Bossaerts *et al*., 2010; Chen and Epstein, 2002; Easley and O'Hara, 2009; Riedel, 2009), applies to the specific case of redeployability. With that approach, investors have too little data to form a single prior for ambiguous redeployability and instead form many priors with unknown likelihoods. Because such vague parameters cannot be matched to assets traded in the market, the market is incomplete and the price for redeployability cannot be derived without restrictions (Björk, 2004). The condition imposed by the maxmin principle is that ambiguity-averse investors count on the minimal utility expected over all possible priors. In that case, the stock market valuation reflects the worst-case scenario for the vague parameters, falling below the level that would occur without ambiguity.

While such undervaluation of assets has been formally (Leippold, Trojani, and Vanini, 2008) and empirically (Anderson *et al*., 2009) demonstrated to be enhanced by ambiguity; that undervaluation has never been identified in the context of redeployability. Besides ambiguity, the natural candidates for predicting undervaluation are the determinants of redeployability. Figure 1 illustrates the known effects and the relationships sought by this study. The known effects, of the determinants of redeployability on true market value and of ambiguity on undervaluation, are shown by the solid lines. The unknown relationships between undervaluation and the determinants of redeployability are marked by the broken lines. Deriving those relationships would enable the application of strategic factor market theory to the stock market. Moreover, comparing the effects of the determinants of redeployability on undervaluation with their effects on true value will test the redeployability paradox. The predictors shown in Figure 1 are used in the next section to build a formal model of stock market undervaluation of redeployability.

Insert Figure 1 here

MODEL

The current section presents a two-part valuation model. The first part replicates the model of Sakhartov and Folta (2015) to derive true value of a firm's redeployable resources that would occur in an efficient market where participants face no ambiguity. The true value of the resources represents their market price that entails equilibrium among market participants who maximize their expected utility. Participants in such a market estimate the expected utility based on their subjective priors for future states of the market, summarized as a probability distribution (Savage, 1954). The second part amends the model of Sakhartov and Folta (2015) to estimate stock market valuation of resources that occurs in a market where participants face ambiguity regarding redeployability. Ambiguity-averse investors in that market use the 'maxmin' approach, counting on the worst-case scenario for the ambiguous redeployability (Gilboa and Schmeidler, 1989). The difference between the two valuations is the undervaluation.

True value of redeployable resources

Like the model in Sakhartov and Folta (2015), the present model considers a firm that initially deploys all its resources in the existing business i. These resources can also be used in the new business j. From the present time $(t=0)$ to the end of the resources' lifecycle $(t=T)$, the firm can redeploy some resources from i to j, or *vice versa*. Margins in businesses i and j are randomly distributed across incumbent firms and specified as geometric Brownian motions:

$$C_{it} = C_{i0} e^{\left[\left(\mu_i - \frac{\sigma_i^2}{2}\right)t + \sigma_i W_{it}\right]} \tag{1}$$

$$C_{jt} = C_{j0} e^{\left[\left(\mu_j - \frac{\sigma_j^2}{2}\right)t + \sigma_j W_{jt}\right]} \tag{2}$$

$$dW_{it} dW_{jt} = \rho\, dt, \tag{3}$$

where C_{it} and C_{jt} are margins at time *t* in i and j; W_{it} and W_{jt} are standard Wiener processes; and μ_i and μ_j are drifts for the margins. As Sakhartov and Folta (2015) explained, the model captures inducements as the current return advantage $(C_{j0} - C_{i0})$; return volatilities σ_i and σ_j; and return correlation ρ. Each of those proxies plays a unique role. Thus, correlation reduces inducements by making returns in the two businesses converge and making any future return advantage in one of them unlikely. Volatility raises inducements by widening confidence bands for returns and expanding future advantages. The current return advantage enhances inducements by putting the band for returns in the new business above the band for the current business. The net margin for firms redeploying resources to business j (i) is lower than the margin C_{jt} (C_{it}), earned by incumbent firms in j (i), by the marginal redeployment cost S. The marginal redeployment cost S is assumed to be certain, invariant with regard to the direction of redeployment, and reduced by relatedness between i and j.

True value of redeployable resources V_0^R represents the net present value of the cash flows expected to be generated over the lifecycle of the firm's resources:

$$V_0^R = \max_{\boldsymbol{M}} E^Q \left[\int_{t=0}^{t=T} e^{-rt} F_t \, dt \right] = \max_{\boldsymbol{M}} \int_{t=0}^{t=T} \left[\int_Q e^{-rt} F_t^q dq \right] dt \, . \qquad (4)$$

In Equation 4, F_t is the uncertain net cash flow of the firm at time t having specific realizations $F_t^q = I_0 \{ [m_{it} C_{it}^q + (1 - m_{it}) C_{jt}^q] - S[\max(0, m_{it} - m_{it-\partial t}) C_{it}^q + \max(0, m_{it-\partial t} - m_{it}) C_{jt}^q] \}$ when margins are C_{it}^q and C_{jt}^q and the firm uses portion m_{it} of resources in i after having used portion $m_{it-\partial t}$ in i at the immediate previous time $t - \partial t$; r is the risk-free interest rate; I_0 is the value initially invested in i; and $\boldsymbol{M} = \{ m_{i0}, m_{i\partial t}, ..., m_{iT-\partial t} \}$ is a vector of resource deployment choices over time. The expectation is taken with respect to the equivalent martingale measure Q (Cox and Ross, 1976; Harrison and Kreps, 1979). The use of Q for the valuation of the resources is equivalent to pricing an option in a market with two securities whose prices match C_{it} and C_{jt}. That market is complete because the number of sources of randomness (*i.e.*, the two standard Wiener processes) matches the number of the traded securities. Redeployability is an option that has a unique price and that is written in that market on the two securities. In line with Savage (1954), the market players pricing the option know the probability distribution for all uncertain parameters in Equation 4.

Because redeployability is an American-type and path-dependent option (Sakhartov and Folta, 2015), Equation 4 is not tractable analytically (Broadie and Detemple, 2004) and is solved numerically with the binomial lattice method of Boyle, Evnine, and Gibbs (1989). In particular, the geometric Brownian motions are approximated with binomial processes, where the next-period margins $C_{it+\partial t}$ and $C_{jt+\partial t}$ take one of four states: $C^u_{it+\partial t}$ and $C^u_{jt+\partial t}$ with probability q^{uu}, $C^u_{it+\partial t}$ and $C^d_{jt+\partial t}$ with probability q^{ud}; $C^d_{it+\partial t}$ and $C^u_{jt+\partial t}$ with probability q^{du}; or $C^d_{it+\partial t}$ and $C^d_{jt+\partial t}$ with probability q^{dd}.[8] The model also discretizes m_{it} so that $m_{it} = \left\{0, \frac{1}{L}, \frac{2}{L}, ..., 1\right\}$, where L is a whole number. Then, the principle of dynamic optimality (Bellman, 1957) is used to compute the resource value expected by market players at time t under the known probability distribution:

$$V_t^R = \max_{m_{it}}\{F_t + e^{-r\partial t}[q^{uu}V^{R,uu}_{t+\partial t}\big|m^*_{it} + q^{ud}V^{R,ud}_{t+\partial t}\big|m^*_{it} + q^{du}V^{R,du}_{t+\partial t}\big|m^*_{it} + q^{dd}V^{R,dd}_{t+\partial t}\big|m^*_{it}]\}, \tag{5}$$

where $V^{R,uu}_{t+\partial t}\big|m^*_{it}$, $V^{R,ud}_{t+\partial t}\big|m^*_{it}$, $V^{R,du}_{t+\partial t}\big|m^*_{it}$, and $V^{R,dd}_{t+\partial t}\big|m^*_{it}$ capture four possible values of resources at the immediate next time $t + \partial t$ conditioned on a selected current choice, m^*_{it} and to be weighted by their respective probabilities. To derive present value of resources V_0^R, calculation starts at time $t = T - \partial t$ with the terminal condition $V_T^R = 0$ and proceeds recursively backward in time. Because future value of resources ($V^{R,uu}_{t+\partial t}$, $V^{R,ud}_{t+\partial t}$, $V^{R,du}_{t+\partial t}$, $V^{R,dd}_{t+\partial t}$), probabilities ($q^{uu}, q^{ud}, q^{du}, q^{dd}$),

[8] The formulas for calculating $C^u_{it+\partial t}$, $C^u_{jt+\partial t}$, $C^d_{it+\partial t}$, $C^d_{jt+\partial t}$, q^{uu}, q^{ud}, q^{du}, q^{dd} are given in Sakhartov and Folta (2015). To avoid the general limitation of Boyle *et al*. (1989), all transition probabilities are checked to be non-negative.

and current net cash flow (F_t) depend on margins (C_{it} and C_{jt}) and redeployment cost (S), the true value is a function $V_0^R = \Omega(C_{i0}, C_{j0}, \sigma_i, \sigma_j, \rho, S)$ studied by Sakhartov and Folta (2015).

Stock market valuation of redeployable resources

The key distinction of stock market valuation of resources is that it enables the context where investors face some ambiguity regarding redeployability. The context is enabled by letting the marginal cost of redeployment S be ambiguous. Although any of the parameters C_{i0}, C_{j0}, σ_i, $\sigma_j, \rho,$ and S may be vague, there are two reasons for focusing on S. First, S is subject to the most durable ambiguity. Thus, parameters C_{i0} and σ_i of the preexisting business i can be estimated from its track record, while parameters $C_{j0}, \sigma_j,$ and ρ describing the new business j are estimable soon after that business emerges. In contrast, redeployment cost S between i and j can be vague to investors long after the inception of j, until a sufficient record on redeployment between i and j emerges. Second, the 'maxmin' approach demands that the worst-case scenario for a vague parameter be found in each state of the nature. From the determinants of redeployability, S is the only parameter for which the worst-case scenario is straightforward regardless of the state of the nature—the highest possible value of S.[9] To enable the multiplicity of investors' priors for S at any time, the marginal redeployment cost is set to follow a geometric Brownian motion:

$$S_t^I = S_0^I e^{\left[\left(\mu_S - \frac{\sigma_S^2}{2}\right)t + \sigma_S W_{St}\right]}, \qquad (6)$$

[9] Although the reported results are based on the model that restricted ambiguity to its most likely source, the marginal redeployment cost; that restriction was relaxed in the robustness checks, as described in Online Appendix A.

where W_{St} is a standard Wiener process uncorrelated with W_{it} or W_{jt}; μ_S is the drift for the cost set to be zero; σ_S is the dispersion of the cost over firms, capturing the extent of ambiguity; and S_0^I the initial value of S_t^I set equal S. Equation 6 parameterizes ambiguity, letting it be absent in a special case $\sigma_S = 0$ where $S_t^I = S$.[10] The model also differentiates ambiguity about S_t^I from uncertainty by stipulating that investors do not know the probabilities of realizations of S_t^I.

Like true value V_0^R of resources, their stock market valuation V_0^I is the net present value of the cash flows accumulated over time. In contrast to V_0^R, V_0^I cannot be computed by investors as an expectation because they do not know the probability distribution of S_t^I. In that case, the valuation involves the 'maxmin' approach of Gilboa and Schmeidler (1989):

$$V_0^I = \max_{\boldsymbol{M}} \min_{Q} \left[\int_{t=0}^{t=T} e^{-rt} F_t \, dt \right] = \max_{\boldsymbol{M}} \int_{t=0}^{t=T} \left[\int_{\underline{Q} \in Q} e^{-rt} F_t^q dq \right] dt \, . \qquad (7)$$

In Equation 7, F_t is still is the net cash flow, but it includes both (a) uncertainty in C_{it} and C_{jt} summarized by investors with the probability distribution and (b) ambiguity about S_t^I whose distribution is unknown to investors. The 'min' in Equation 7 captures ambiguity aversion with which investors count on the worst-case scenario $\underline{Q}$ for the ambiguous parameter. In this model, investors integrate F_t over the known probability distribution for C_{it} and C_{jt} but count on the highest possible value S_t^{Iu} for the ambiguous redeployment cost. That restriction complements the standard option pricing by enabling the detection of the unique price V_0^I in the incomplete

[10] The assumption can be easily relaxed by introducing a bias in the expected value for redeployment costs. In that case, the resulting misevaluation of resources would include the manifestation of the ambiguity aversion and the distortion (in contrast to the lack) of the information available to investors. The current study focuses on the former and assumes away the latter.

market, where S_t^I does not have a counterpart traded security.[11] Like V_0^R, market valuation V_0^I is estimated numerically using the binomial lattice method (Boyle *et al.*, 1989). Because W_{St} is specified uncorrelated with W_{it} or W_{jt}, cost S_t^I can be discretized separately from C_{it} and C_{jt}, so that $S_{t+\partial t}^{Iu} = e^{\sigma_S \sqrt{\partial t}} S_t^I$. After the discretization, the Bellman's equation to estimate stock market valuation of the resources recursively backward in time is

$$V_t^I = \max_{m_{it}}\{F_t(S_t^{Iu}) + e^{-r\partial t}[q^{uu}V_{t+\partial t}^{Iuu}(S_{t+1}^{Iu})\big|m_{it}^* + q^{ud}V_{t+\partial t}^{Iud}(S_{t+1}^{Iu})\big|m_{it}^* + q^{du}V_{t+\partial t}^{Idu}(S_{t+1}^{Iu})\big|m_{it}^* + q^{dd}V_{t+\partial t}^{Idd}(S_{t+1}^{Iu})\big|m_{it}^*]\}. \tag{8}$$

Like V_0^R, stock market valuation V_0^I still depends on $C_{i0}, C_{j0}, \sigma_i, \sigma_j$, and ρ. Besides, V_0^I depends on the dispersion σ_S of priors for redeployment costs shaping the worst-case scenario (S_t^{Iu}). Thus, stock market valuation is a function $V_0^I = \Phi(C_{i0}, C_{j0}, \sigma_i, \sigma_j, \rho, \sigma_S)$. Finally, stock market undervaluation of resource redeployability is an analytically intractable function $(V_0^R - V_0^I) = \Lambda(C_{i0}, C_{j0}, \sigma_i, \sigma_j, \rho, S, \sigma_S)$ that is analyzed numerically in the next section.

RESULTS

The analysis involves three parts. First, the known effect of ambiguity on the undervaluation is validated. Second, the undervaluation is related to each determinant of redeployability. Third, the

[11] The use of the 'maxmin' principle to derive market prices implies that the market is dominated by players with the strongest ambiguity aversion. There are several rationales for that approach. First, models with a representative agent having the strongest ambiguity aversion were used to derive market prices (Chen and Epstein, 2002; Epstein and Wang, 1994). Second, the explicit derivation of the equilibrium price for the option with ambiguity may be a futile task with the current state of asset pricing. Staum (2008: 511–513) explains: 'There is yet no fully developed theoretical framework for pricing derivative securities in incomplete markets… Although equilibrium concepts might be useful in pricing, it is too ambitious to attempt to construct an entire equilibrium.' Third, Easley and O'Hara (2009) used a simplified equilibrium model to show that the presence of at least some strongly ambiguity-averse market players reduces the equilibrium price. Therefore, while a representative agent model aggregates various degrees of ambiguity aversion, it does not qualitatively alter the fact of the undervaluation. Fourth, Drechsler (2013) provided initial empirical evidence that stock investors facing ambiguity price securities based on the worst-case scenario. Finally, the quotes of stock analysts in the example of Apple support the extreme ambiguity aversion of stock market players.

known effect on true resource value is reconfirmed for each determinant of redeployability and, to test the redeployability paradox, compared to its effect on the undervaluation.[12]

Effect of investor ambiguity about redeployment cost on resource undervaluation

Figure 2 illustrates how the undervaluation relates to ambiguity about redeployment costs. The undervaluation is present and enhanced by ambiguity confirming the known result (Anderson *et al.*, 2009; Leippold *et al.*, 2008). With the parameter values used (hereinafter reported below the respective figure), the undervaluation may be as high as 9.6 percent. While there is little surprise in the fact that ambiguity-averse investors undervalue resources in the presence of ambiguity, the result illustrates both the need to separate investor valuation from true resource value and the possibility of such separation. That result serves as a starting point for exploring whether the undervaluation is systematically related to the known determinants of resource redeployability.

Insert Figure 2 here

Effect of current return advantage on resource undervaluation

Value implications of the first proxy for inducements, the current return advantage, are shown in Figure 3. Panel B reveals two relationships uniquely derived in this study. First, when ambiguity is present, undervaluation has an inverse U-shaped relationship with current advantage. The result has the following interpretation. When current returns are much lower in the new than in the initial business (at the left end of Panel B), redeployment never occurs and redeployability cannot be undervalued. When current returns are much higher in the new business (at the right margin of Panel B), instant redeployment of all resources to the new business occurs, canceling implications of future ambiguity. Only when the two businesses have similar current returns (in

[12] The model is computationally intensive. With 200 time steps, the binomial lattice contains 2,727,101 nodes. A processor with 3.4GHz frequency and 8GB memory spends 35 minutes to evaluate the undervaluation for a single combination of parameters.

the middle part of Panel B) are future redeployments likely, and in that case ambiguity disturbs the valuation. Second, the shapes of the lines in Panel B show that undervaluation is more sensitive to the current advantage when ambiguity is higher. Thus, ambiguity positively (negatively) moderates the positive (negative) effect of low (high) current return advantages on the undervaluation.

Insert Figure 3 here

Panel A replicates the positive effect of current return advantage on true resource value, derived by Sakhartov and Folta (2015). The comparison of the panels of Figure 3 reveals the condition for the redeployability paradox to hold with respect to the current return advantage. Given that the left parts of the dash-dot and the solid lines are upward-sloped for both true resource value and the undervaluation, the redeployability paradox occurs with negative current return advantages. Conversely, given that the current return advantage simultaneously enhances the true resource value and reduces the undervaluation in the left-hand portions of the dash-dot and the solid lines, the redeployability paradox is rejected with positive current return advantages.

Effects of return volatilities on resource undervaluation

Figure 4 shows the value implications of the second proxy for inducements, return volatility.[13] Panel B depicts two newly derived relationships. First, the upward-sloped lines indicate that volatility enhances the stock market undervaluation of redeployability. That direct effect of volatility can be interpreted as follows. When returns are certain (at the left end of Panel B), strong differences in future returns between the two businesses are unlikely and the value of redeployability collapses to zero. There is just nothing to undervalue in that case. Conversely,

[13] To reduce the dimensionality of the visual representation, return volatilities are captured by a single parameter $\sigma = \sigma_i = \sigma_j$.

when returns are very uncertain (at the right end of Panel B), future returns have very wide confidence bands and strong differences between the businesses occur. In that case, future redeployment is very likely too, but it is hard to evaluate due to ambiguity. Second, the relative positions of the lines in Panel B show that ambiguity enhances the effect of volatility on the undervaluation.

Insert Figure 4 here

Panel A reconfirms the known positive effect of volatility on true resource value (Sakhartov and Folta, 2015). Comparison of that result to Panel B demonstrates that the redeployability paradox holds universally with respect to volatility. Thus, at any volatility, the dash-dot and the solid lines are upward-sloped for both true resource value and undervaluation.

Effect of return correlation on resource undervaluation

Figure 5 depicts value implications of the third proxy for inducements, return correlation. Panel B reveals two newly derived effects. First, the downward-sloped lines suggest that correlation reduces the stock market undervaluation of redeployability. That direct effect of correlation can be explained as follows. When returns in the existing and the new businesses are perfectly positively correlated (at the right end of Panel B), those returns tend to converge and strong differences between them are unlikely. The value of redeployability collapses to zero in that case, and there is nothing to undervalue. Conversely, when returns are perfectly negatively correlated (at the left end of Panel B), such returns diverge from each other and strong differences between them are likely. In that case, future redeployment is very likely, but its evaluation is hampered by ambiguity. Second, the relative position of the lines in Panel B demonstrates that ambiguity exacerbates the negative effect of volatility on undervaluation.

Insert Figure 5 here

Panel A recreates the known negative effect of correlation on the true resource value (Sakhartov and Folta, 2015). The comparison of that result to Panel B demonstrates that the redeployability paradox holds universally with correlation. Thus, at any correlation, the dash-dot and the solid lines are downward-sloped for both true resource value and undervaluation.

Effect of redeployment cost on resource undervaluation

The value implications of redeployment costs are displayed in Figure 6. Panel B reveals two newly derived relationships. First, when some ambiguity is present, undervaluation has an inverse U-shaped relationship with redeployment costs. The right downward-sloping parts of the dash-dot and the solid lines in Panel B can be explained as follows. With very high redeployment costs (at the right end of Panel B), the objective value of redeployability collapses to zero, so undervaluation is impossible. The upward slopes of the left parts of the same two lines in Panel B can be interpreted as follows. At the left margin, the mean for investors' priors for the marginal redeployment cost is zero. Because the natural low bound for non-negative redeployment costs is zero too, the worst-case scenario for redeployment costs is also zero and ambiguity becomes inconsequential.[14] Second, the position of the lines in Panel B shows that ambiguity makes undervaluation more sensitive to redeployment costs. Thus, ambiguity positively (negatively) moderates the positive (negative) effect of low (high) redeployment costs on undervaluation.

Insert Figure 6 here

Panel A reestablishes the negative effect of redeployment costs on true resource value (Sakhartov and Folta, 2015). The comparison of that result to Panel B tests the redeployability

[14] In the marginal case, where $S = 0$, parameter S_t^I becomes deterministic, irrespective of σ_S, because S_t^I may not be negative.

paradox. Given the downward slopes of the dash-dot and the solid lines in the right-hand parts of both panels, the paradox occurs with medium-to-high redeployment costs. Because redeployment costs simultaneously reduce true resource value and enhance the undervaluation in left parts of the dash-dot and the solid lines, the paradox is rejected with low redeployment costs.

Relevance of results

The relevance of the results derived depends on the applicability of the model to the contexts of resource valuation. A substantial effort has been made to verify that the model is appropriate. First, the operationalization of redeployability was taken in its entirety from previous research. Second, that operationalization was amended to account for ambiguity, based on the established conceptualization of ambiguity aversion. Third, new findings are explained intuitively, with the intuition general across alternative specifications. Finally, multiple tests were run to ensure that the reported results are not artifacts of the parameter values used. In particular, the results in each figure were re-estimated for a range of alternative values of the parameters held constant in that figure. While the economic significance of the reported relationships depends on the specific parameter values; the theoretical predictions summarized below are robust. A summary of the robustness tests can be found in Online Appendix A.[15]

Summary of theoretical results

Below is a summary of how the undervaluation of redeployable resources can be predicted.

> H1: Stock market undervaluation of resources is enhanced by investor ambiguity regarding the cost of resource redeployment between the original business and the new business.

[15] In addition, Online Appendix B presents data on stock market valuation of Apple Inc. around the announcement of iPhone in 2007. The data illustrate the applicability of the model designed for the real context of stock market valuation of resources.

H2: Stock market undervaluation of resources has an inverse U-shaped relationship with the current return advantage of the new business over the original business.

H3: Stock market undervaluation of resources is enhanced by volatility of returns in the original business or the new business.

H4: Stock market undervaluation of resources is reduced by correlation of returns between the original business and the new business.

H5: Stock market undervaluation of resources has an inverse U-shaped relationship with the cost of resource redeployment between the original business and the new business.

H6: With low values of the current return advantage, the positive effect of the current return advantage on stock market undervaluation of resources is positively moderated by investor ambiguity about redeployment costs.

H7: With high values of the current return advantage, the negative effect of the current return advantage on stock market undervaluation of resources is negatively moderated by investor ambiguity about redeployment costs.

H8: The positive effects of volatility of returns in the original business and the new business on stock market undervaluation of resources are positively moderated by investor ambiguity about the redeployment cost.

H9: The negative effect of correlation of returns between the original business and the new business on stock market undervaluation of resources is negatively moderated by investor ambiguity about the redeployment cost.

H10: With low values of redeployment costs, the positive effect of the redeployment cost on stock market undervaluation of resources is positively moderated by investor ambiguity about the redeployment cost.

H11: With moderate and high values of redeployment costs, the negative effect of the redeployment cost on stock market undervaluation of resources is negatively moderated by investor ambiguity about the redeployment cost.

Except for H1, the above predictions are uniquely derived by the present study. A tentative direction for empirically verifying those theoretical predictions is outlined immediately below.

TOWARD EMPIRICAL IDENTIFICATION OF RESOURCE UNDERVALUATION

The derived results should be amenable to empirical analysis, although some challenges are worth mentioning. For example, it is important to find proxies for ambiguity and the determinants of redeployability that reflect the implied conceptual meanings. The multiplicity of destinations for resource redeployment must be addressed. Also, the contexts where the market undervaluation of resources is revealed need to be identified. Finally, alternative sources for the undervaluation should be ruled out. While the complete resolution of those empirical challenges is outside of the scope of this theoretical study, the following tentative guidance is offered to mitigate them.

Empirical models seeking to test the deduced hypotheses can take the form:

$$\begin{aligned} Y_{it} = {} & \beta_0 + \beta_1 X_i + \max_j\{0, \beta_2\sigma_S + f(S_{ij}) + g(C_{jt} - C_{it}) + \beta_3\sigma_i + \beta_4\sigma_j \\ & + \beta_5\rho_{ij} + \beta_6\sigma_S f(S_{ij}) + \beta_7\sigma_S g(C_{jt} - C_{it}) + \beta_8\sigma_S\rho_{ij}\} + \varepsilon. \end{aligned} \tag{9}$$

Variable Y_{it} is an empirically measurable manifestation of the stock market undervaluation of resources of firms in industry i in year t. For instance, Y_{it} may directly represent the mispricing or count deviations of firms' choices from the behavior expected in efficient markets. In particular, a premium paid by a bidder for a target may proxy for the undervaluation (Laamanen, 2007) if the bidder acted on the undervaluation of the target detected during the pre-deal due diligence. Similarly, Y_{it} can be measured as the likelihood that a target accepts a bidder's stock as a means of payment in an acquisition, if the target has detected the undervaluation of the bidder's stock (Faccio and Masulis, 2005). Undervaluation Y_{it} can also be measured through the likelihood that public firms invite private equity investors (Folta and Janney, 2004) or private firms invite venture capitalists (Gompers and Lerner, 2001) to support resource deployment strategies, when redeployable resources of such firms are undervalued by the market.

All β's in Equation 9 are the estimated coefficients. Vector X_i involves alternative predictors of deviations of firms' choices from the behavior expected in efficient markets. Parameter σ_S represents the ambiguity faced by market investors with regard to redeployability. Thus, intensity of prior redeployments from industry i may inversely capture σ_S if investors infer redeployment costs from past redeployments. Variance of analyst forecasts for firms in industry i may be another measure for σ_S. Inducements can be operationalized as proposed by Sakhartov and Folta (2015). In particular, current returns C_{it} and C_{jt} can be taken from business segment data as mean industry return on asset (ROA) at time t. Volatilities σ_i and σ_j can be computed as standard deviations of industry ROA. Return correlation ρ_{ij} can be approximated with correlation of mean ROA between industries. Costs S_{ij} of redeploying resources between industries i and j can be estimated as dissimilarity of resource requirements between those industries, previously measured with industry occupational profiles (Coff, 1999) or input profiles (Brush, 1996).

Function f and g in Equation 9 denote arbitrary functions (*e.g.*, polynomial) fitting the curves in Panel B of Figure 6 and Panel B of Figure 3, respectively. A key feature of Equation 9 is that which of multiple new industries causes the strongest undervaluation is often unknown. By iterating over all possible industries j, the maximum likelihood estimation can find j^* as the choice with the highest value of the maximum likelihood. Accordingly, the estimation requires measurement of C_{jt}, σ_j, ρ_{ij}, and S_{ij} across all industries. Equation 9 can be evaluated with the maximum likelihood estimation after making a distributional assumption about the error term ε.

DISCUSSION

The existence of undervaluation of resources in the factor market is the key premise of strategic factor market theory. Alleged to apply to corporate acquisitions, the premise confronted grave skepticism of proponents of market efficiency, who insist that undervaluation in the stock market cannot be exploited. Even if underpricing existed, it would be considered to be short-lived and unpredictable. Empirical studies of corporate acquisitions sustained that contention. Such studies either assertively denied that bidders could gain from the target underpricing, or assumed the undervaluation instead of establishing it. The tension was not resolved in the theoretical work that modeled a game between a buyer and a seller of resources but did not capture the behavior of diffuse stock investors, who are distant from actual resource deployment and face ambiguity about resource properties. This study attempts to establish theoretically the existence of stock market undervaluation of a firm's resources. While not considering the corporate acquisition process in its entirety, the study takes three steps to explain when stock markets undervalue targets enabling excess returns to acquirers.

First, the study reviews two separate streams of research to identify a likely source of stock market undervaluation of a firm, *resource redeployability*, the option for the evaluated firm to withdraw its resources from the existing business and redeploy them to a new business. The first stream evaluated redeployability under the assumption that its value is realized in the efficient market, where players know a probability distribution for outcomes and instantly revise estimates for redeployability with the arrival of new data. While that research uncovered the determinants of redeployability, it was bounded by the assumption committed. However, when a new business has just emerged and no redeployment to it from the existing business has occurred yet, market players have no data with which to assess a probability distribution. The second stream of research reviewed, while being agnostic about the specifics of redeployability, relaxed the assumption that evaluators always know the probability distribution. That stream focused on *ambiguity*, a situation in which there is insufficient information about an event to represent it with a probability distribution. Research on ambiguity identified uniqueness of the evaluated event as the origin of ambiguity. The key implication of ambiguity is ambiguity aversion, with which people discount events with unknown probabilities. Empirical studies have confirmed that stock investors are ambiguity-averse. With ambiguity, investors do not efficiently process news, and count instead on the worst-case scenario, thus underpricing the evaluated stock. The review concludes that the idea that uniqueness is the origin of ambiguity is applicable to the case where stock investors evaluate redeployability to a new business before having observed redeployment from the existing business. Therefore, the insights into the undervaluation of assets in the presence of ambiguity can be integrated into the valuation of redeployability in the stock market.

Second, the study builds a model based on established methods for valuing resources both in the efficient market and in the market with ambiguity. The model delivers two novel insights. The first insight is that undervaluation, which was known to derive from ambiguity, can be predicted using the determinants of redeployability. That result establishes theoretically the relevance of strategic factor market theory to corporate acquisitions. The model suggests an operationalization that can be tested in future studies of corporate acquisitions instead of either assertively refuting or assuming undervaluation. The operationalization may also help managers seek out contexts where corporate acquisitions can add the most value. The second novel insight is the existence of the redeployability paradox: the parameters that make redeployability more valuable objectively can also make it more undervalued in stock markets. The paradox was not part of extant empirical tests, which conflated true value of redeployable resources with their stock market valuation. Moreover, the model derives the boundary conditions for the paradox.

Finally, the study takes an additional step and compiles an example illustrating how the theory of stock market undervaluation of redeployability applies to a real firm. That example, described in Online Appendix B, considers the stock market valuation of redeployability of resources of Apple Inc. from computers to smartphones. While not meant to be a fully-developed case study, the example illustrates that the need for the stock market to assess redeployability of resources from computers to smartphones had emerged long before such redeployments created a record sufficient to form a probability distribution. Moreover, the example reveals that, among the known determinants of redeployability, the costs of redeploying resources from computers to the emerging smartphone business was the most persistent source of ambiguity. Facing that ambiguity, stock market analysts, and the market in general, behaved in a way consistent with ambiguity aversion. In particular, stock analysts following Apple Inc. around the time of the iPhone release explicitly acknowledged that they still assigned zero (*i.e.*, worst possible) value to the redeployment option long after the option had emerged and become evident to them. Additional circumstantial evidence of ambiguity aversion is revealed in the fact that positive news regarding redeployability of resources (from computers to smartphones) had little effect on the firm's stock price. Ultimately, the evidence in support of stock market undervaluation is reinforced by contrasting the data about Apple Inc. with several alternative interpretations.

Limitations

The valuation model extends strategic factor market theory. However, the model has some limitations. Some critics may argue that the numerical completion of the model is 'too inaccurate to yield valid theoretical insights' (Davis, Eisenhardt, and Bingham 2007: 480). In addition to the model's reliance on the established binomial lattice method, extensive tests indicate that the results are robust across a wide range of parameters, validating the generalizability of the results.

A caveat may be raised that the formalization of redeployability, taken in its entirety from Sakhartov and Folta (2015), is oversimplified. Thus, redeployment costs are assumed to depend only on the applicability of resources to a new business, and therefore do not capture other obstacles to entering that business. Such obstacles might involve organizational inertia and competitive or institutional barriers to entering a business. Although such obstacles are important attributes of real contexts, adding them to the model can make it intractable, and make the results uninterpretable. Therefore, the modeling of redeployability together with those features is left for future efforts.

Another limitation is that the model considers only one source of undervaluation, resource redeployability. Of course, there may be many other reasons for mispricing a firm. For example, stock market investors can also face ambiguity that derives from uniqueness of a combination of businesses with complementary resources (Litov *et al*., 2012), or from uniqueness of synergy between the bidder and the target in a corporate acquisition (Barney, 1988). This study does not attempt to create a comprehensive model of all possible types of resource mispricing. Rather, to make the model tractable and reliable, the study uses one important source of undervaluation, which can be formalized based on the existing insights and established formal techniques, and leaves the study of other sources to future models. By keeping alternative sources of undervaluation constant, the model enables a clean experiment with respect to the particular causal mechanism that leads to mispricing of resources.

Some readers may argue that this study uses the developed model too narrowly, given that the model could accommodate additional contexts, other than the stock market, in which undervaluation of redeployability is observed. Thus, redeployability can be undervalued by the firm's private investors, by managers, by debtors, or by outsiders who buy specific resources but not the whole firm. A private startup, like a public firm, may have an opportunity to redeploy its resources to another business, and that option can be mispriced by stakeholders. Moreover, the option for a firm to introduce a new generation of a product, rather than to simply move resources to a new business, can be mispriced. While those contexts are not explicitly discussed in the study, they can nevertheless be described with the model developed here. The broad applicability of the model, however, does not suggest that the present study should necessarily investigate all of its possible uses. Rather, the model, while unintentionally general, was built to address the specific controversial issue highlighted in the title of the present study.

Three additional ramifications of ambiguity, not directly addressed by this study, are worth mentioning. First, the study does not explicitly model a game, where some market players resolve ambiguity earlier than other players and profit by buying undervalued resources. While adding that game among multiple stock market players is intriguing, the already complex model of the American-type option with redeployment costs will likely become intractable. Moreover, when deals between market players facing asymmetric ambiguity propagate, ambiguity vanishes; that possibility is accommodated by the model with various extents of ambiguity in the market.

Second, the evaluated firm's managers also face some ambiguity and may not recognize and attain the true resource value, used as a benchmark for deriving the undervaluation. While an important research topic by itself, that ramification does not change the fact that the evaluated firm in that case would still be valued below the level that can be realized by its buyer. Third, redeployability of a firm's resources may also be ambiguous to its rivals, protecting the potential competitive advantage of that firm and increasing its true value. Until the redeployment is exercised, that advanced true value remains the potential that is untapped by the firm. However, when the firm enacts that potential and starts redeploying resources, such redeployment becomes less unique, thus reducing ambiguity faced by both stock market investors and the firm's rivals.

Finally, three limitations of the illustrative example should be discussed. First, whereas evidence in the case is examined in light of alternative explanations, the list of those explanations is not exhaustive. Second, the case retrospectively interprets a phenomenon that may never repeat. However, the current stock market reaction to redeployability of resources of Apple Inc. to self-driving cars appears to replicate the pattern. Although Apple Inc. is known to have invested in autonomous cars with plans to release them in 2020, and stock market analysts anticipate that the car business has an upside potential for Apple Inc., those analysts consider that potential too ambiguous to count on it in their estimates.[16] The third limitation is that despite rich circumstantial evidence, the illustration cannot provide absolute proof of stock market undervaluation of Apple Inc. due to redeployability. Such proof is impossible due to the latency

[16] In its report of June 6, 2016, UBS considers six scenarios for the valuation of Apple Inc. The only scenario counting on the car business generates the stock price range between 160 dollars and 200 dollars. The recommended target price is 115 dollars and the contemporaneous market price is 99 dollars, seeming to indicate that neither the analyst nor the market counts on redeployability of the firm's resources to cars. UBS explains: 'Our last scenario is a positive conjecture about an Apple Car and should be recognized as a moonshot. It's highly unlikely we could accurately model how Apple plans to enter the automotive space,' and 'Investors are skeptical of impact from the Apple Car.'

of true resource value. If it were possible to establish proof with a qualitative case study, that method would have been preferable to the formal model.

Broader implications of stock market undervaluation of redeployability

The study may be interpreted as arguing that resources are always undervalued in stock markets. This paper does not make that point. There are in fact many contexts in which resources are overvalued. Leaving the overvaluation to other research, the study focuses on undervaluation, which is important for strategizing in factor markets. That focus speaks to the following broader implications.

- The operationalization of stock market undervaluation motivates future empirical work on arbitrage strategies linked to resource mispricing in the stock market. Contexts that can be explored with that operationalization involve payment of bid premiums (Laamanen, 2007) and the use of the bidders' stock as the means of payment (Faccio and Masulis, 2005) in corporate acquisitions, private equity issues by public firms (Folta and Janney, 2004), and venture capitalist funding (Gompers and Lerner, 2001).
- Resource undervaluation can result in financial constraints bounding efficient resource deployment strategies (Mahoney and Pandian, 1992). Firms dependent on public equity in their resource redeployment may not receive the money the strategy really deserves. That possibility suggests that studies simply relating firms' stock market value to redeployability (Anand and Singh, 1997; Montgomery and Wernerfelt, 1988) are unclear in terms of whether they capture true resource value or value as enabled by stock market investors.
- Research on information asymmetries has considered intangible resources, which need not be withdrawn from their current use to be leveraged in new uses, but which are difficult to

price due to ‘causal ambiguity’ (Dierickx and Cool, 1989), ‘social complexity’ (Barney, 1991), and a lack of credible accounting records (Aboody and Lev, 2000). Empirical studies (Boone and Raman, 2001; Chaddad and Reuer, 2009; Chan, Lakonishok, and Sougiannis, 2001; Laamanen, 2007) have related firms’ value or choices to attributes of intangible resources. The present study complements that work by predicting the mispricing of tangible redeployable resources, which must be withdrawn from current uses to be reallocated elsewhere.

- Undervaluation of redeployable resources in the stock market provides a new theoretical justification for the existence of multi-business firms. When a firm focused on a declining business can sell that business only with a discount based on the currently unfavorable performance, redeployment of part of the resources underutilized in that business to another better performing business becomes a reasonable alternative to costly divestiture. Laurent Beaudoin mentioned that rationale to explain why Bombardier Inc. redeployed half of its plants from a declining snowmobile business to the mass transit business in 1973, instead of divesting the snowmobile business (Baghai *et al*., 1997).

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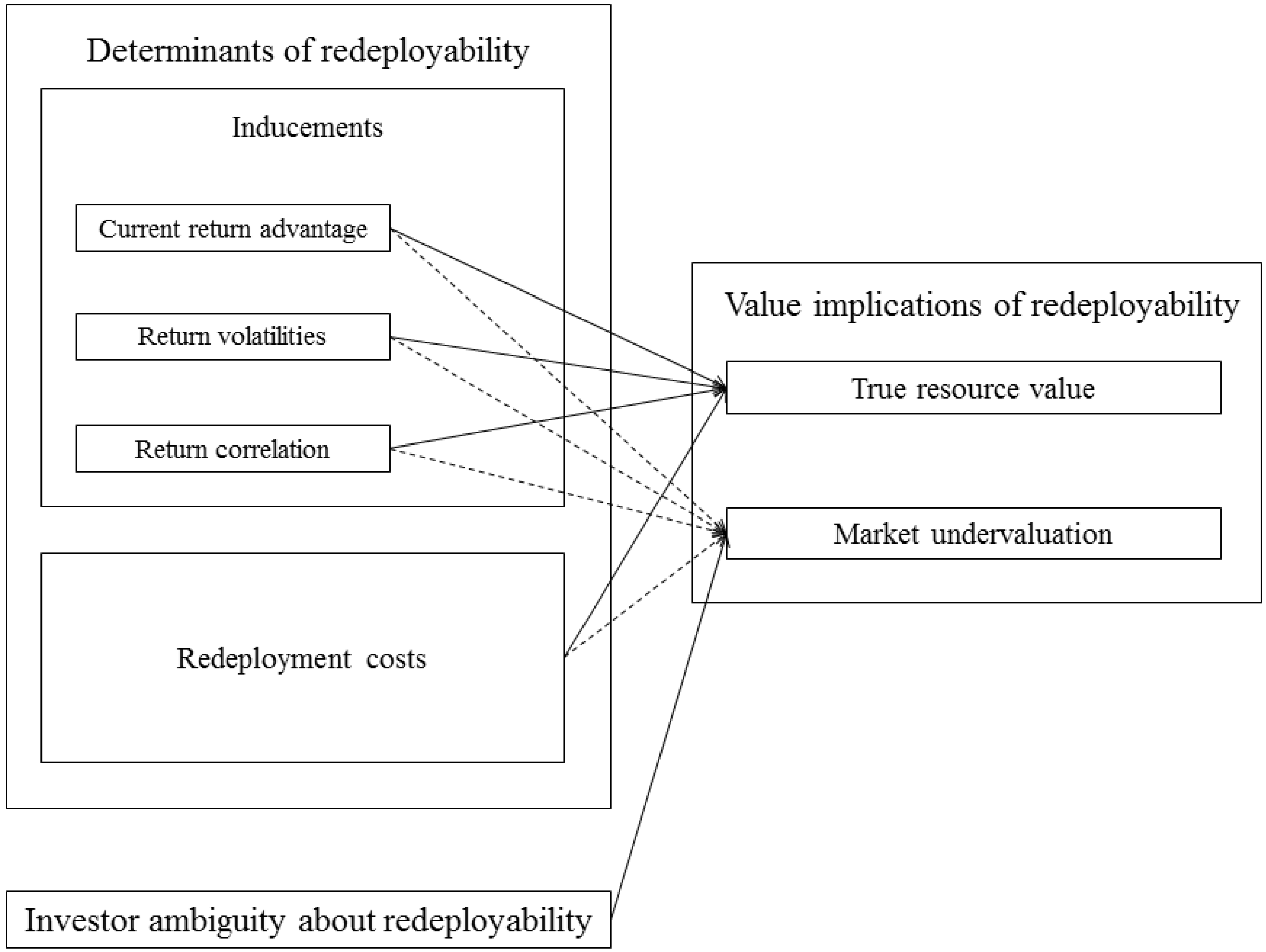


Figure 1. Determinants and value implications of resource redeployability

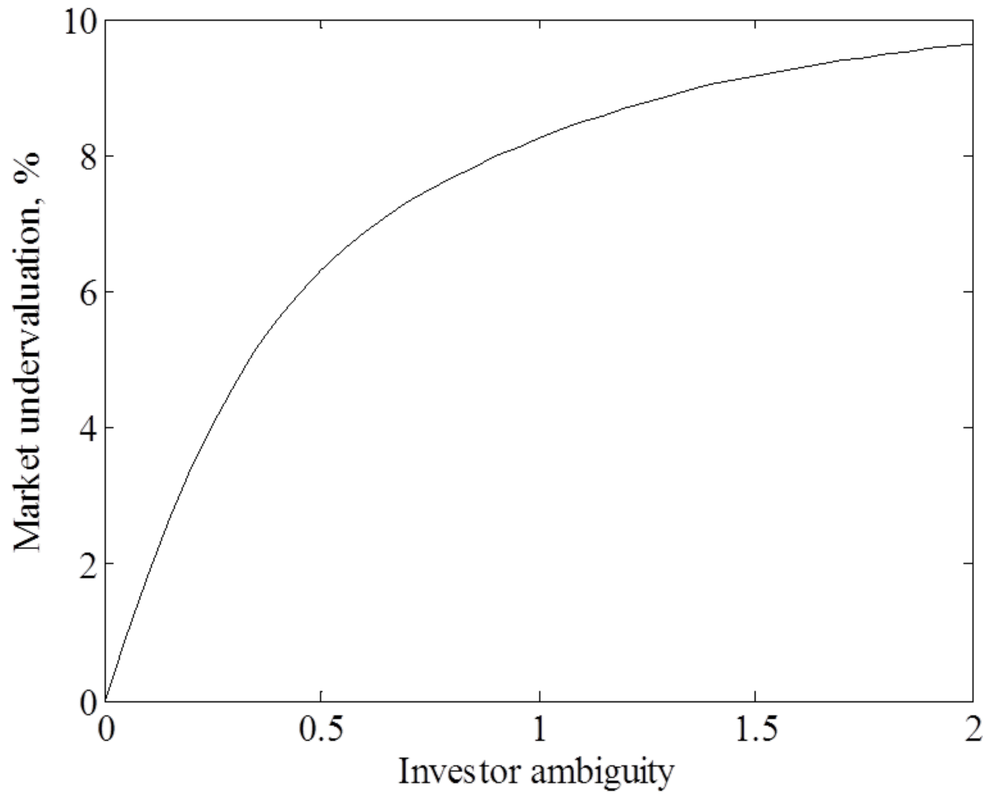
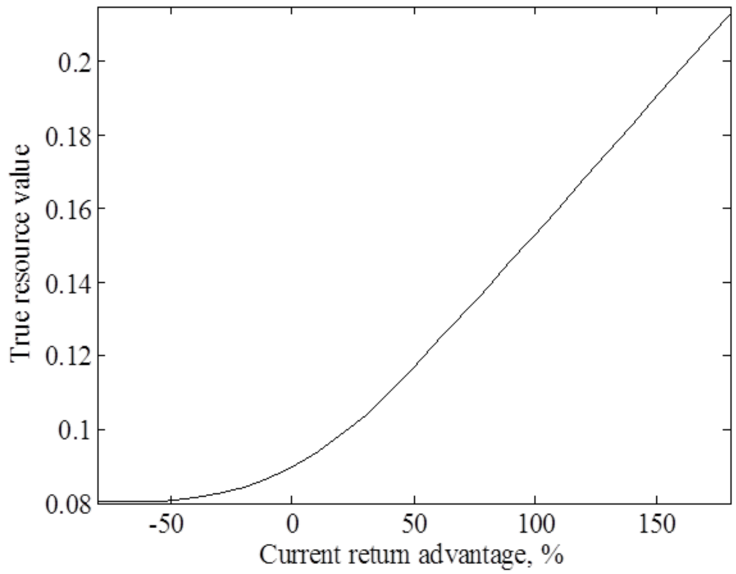
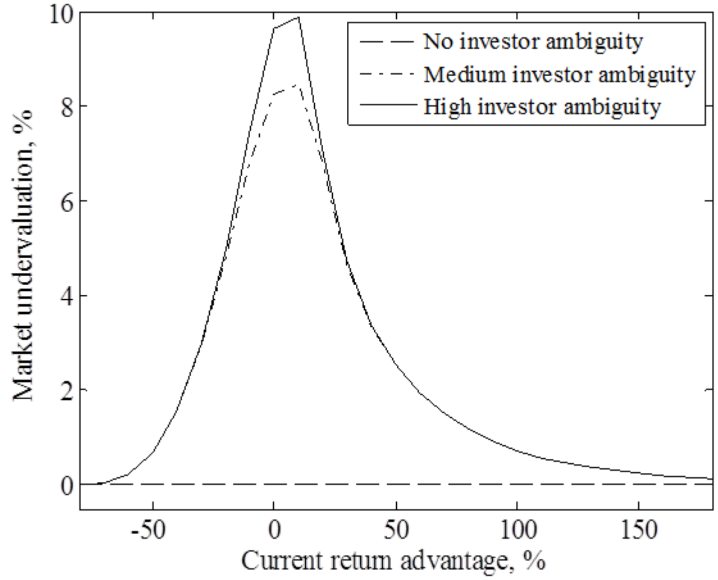


Figure 2. Effect of investor ambiguity on market undervaluation

Market undervaluation of redeployable resources is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 7) from their true value (V_0^R) (calculated with Equation 5) and scaling the difference by the true value (V_0^R). Investor ambiguity is volatility (σ_S) of investor beliefs about the marginal redeployment cost involved in Equation 6. Other parameters used for calculations include current market returns $C_{i0} = C_{j0} = 0.08$; return volatilities $\sigma_i = \sigma_j = 0.5$; return correlation $\rho = 0$; marginal redeployment cost $S = 10$; risk-free interest rate $r = 0.08$; length of the resource lifecycle $T = 1$; number of time discretization steps $N = 200$; and the number of capacity discretization steps $L = 1$. Without loss of generality, the value of the originally invested resources I_0 is standardized to unity.



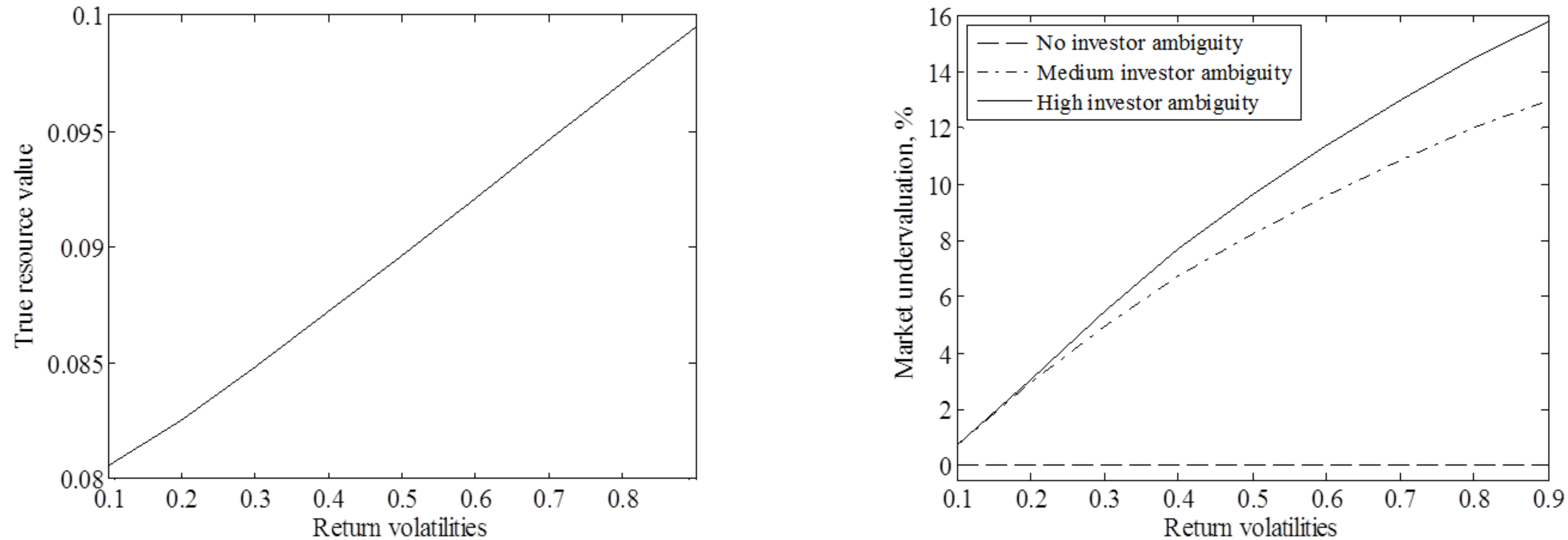
A. Effect of current return advantage on true value



B. Effect of current return advantage on market undervaluation

Figure 3. Value implications of current return advantage

True resource value (V_0^R) is computed with Equation 5. Market undervaluation is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 7) from their true value (V_0^R) and scaling the difference by the true value (V_0^R). Current return advantage involves parameters from Equations 1 and 2 and is calculated by subtracting current returns in the original market C_{i0} from current returns in the new market C_{j0} and scaling the difference by current returns in the original market C_{i0}. Investor ambiguity is volatility (σ_S) of investor beliefs about the marginal redeployment cost, taking zero $\sigma_S = 0$, medium $\sigma_S = 1$, and high $\sigma_S = 2$ values. Other parameters used for calculations include return volatilities $\sigma_i = \sigma_j = 0.5$; return correlation $\rho = 0$; marginal redeployment cost $S = 10$; risk-free interest rate $r = 0.08$; length of the resource lifecycle $T = 1$; number of time discretization steps $N = 200$; and the number of capacity discretization steps $L = 1$. Without loss of generality, the value of the originally invested resources I_0 is standardized to unity.

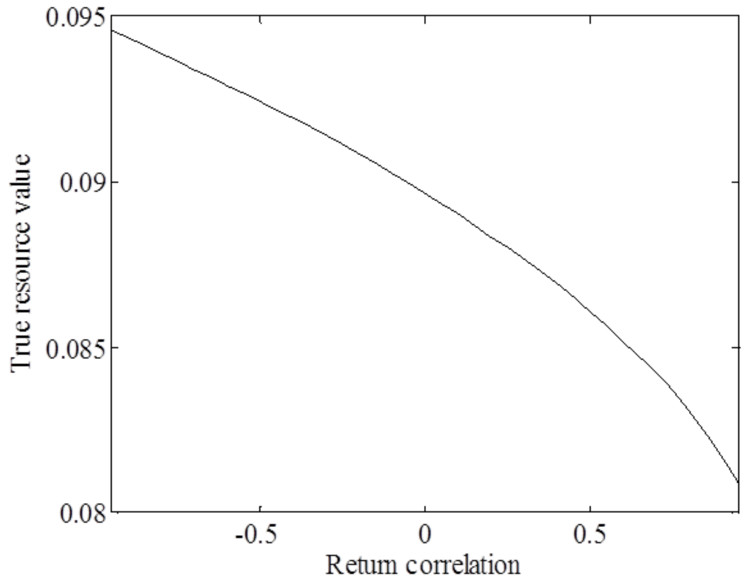


A. Effect of return volatilities on true value

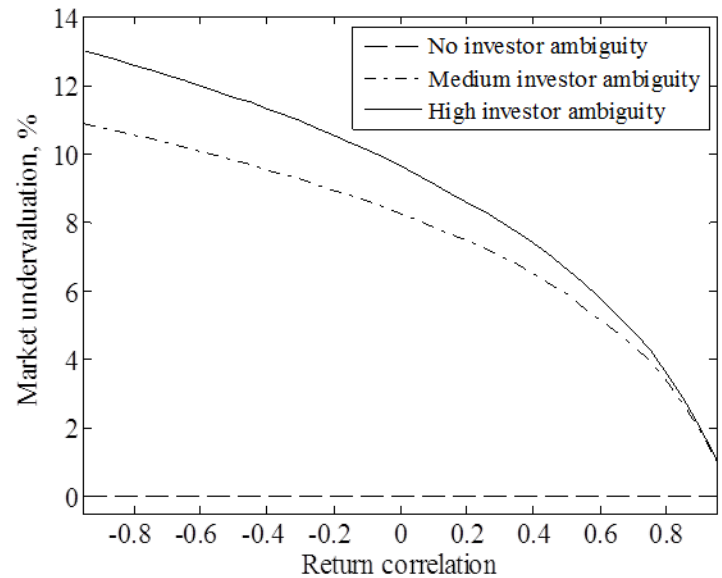
B. Effect of return volatilities on market undervaluation

Figure 4. Value implications of return volatilities

True resource value (V_0^R) is computed with Equation 5. Market undervaluation is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 7) from their true value (V_0^R) and scaling the difference by the true value (V_0^R). Return volatilities from Equations 1 and 2 are set equal to each other $\sigma_i = \sigma_j$. Investor ambiguity is volatility (σ_S) of investor beliefs about the marginal redeployment cost, taking zero $\sigma_S = 0$, medium $\sigma_S = 1$, and high $\sigma_S = 2$ values. Other parameters used for calculations include current market returns $C_{i0} = C_{j0} = 0.08$; return correlation $\rho = 0$; marginal redeployment cost $S = 10$; risk-free interest rate $r = 0.08$; length of the resource lifecycle $T = 1$; number of time discretization steps $N = 200$; and the number of capacity discretization steps $L = 1$. Without loss of generality, the value of the originally invested resources I_0 is standardized to unity.



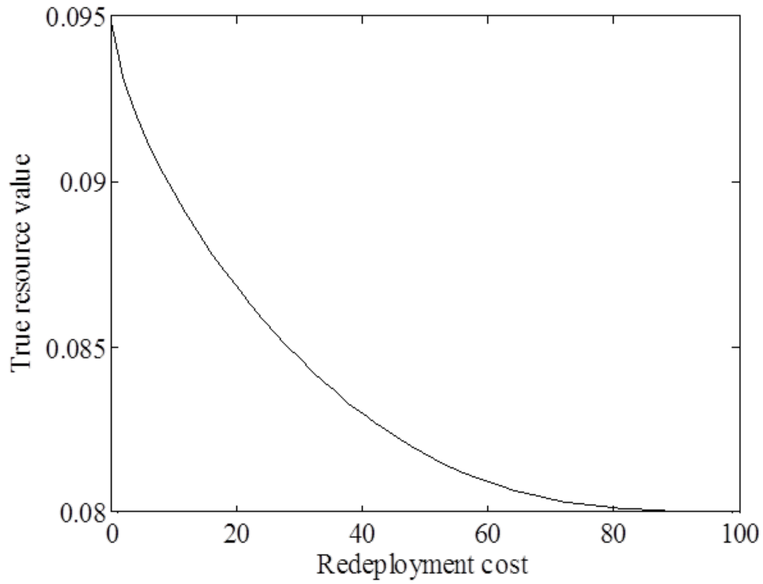
A. Effect of return correlation on true value



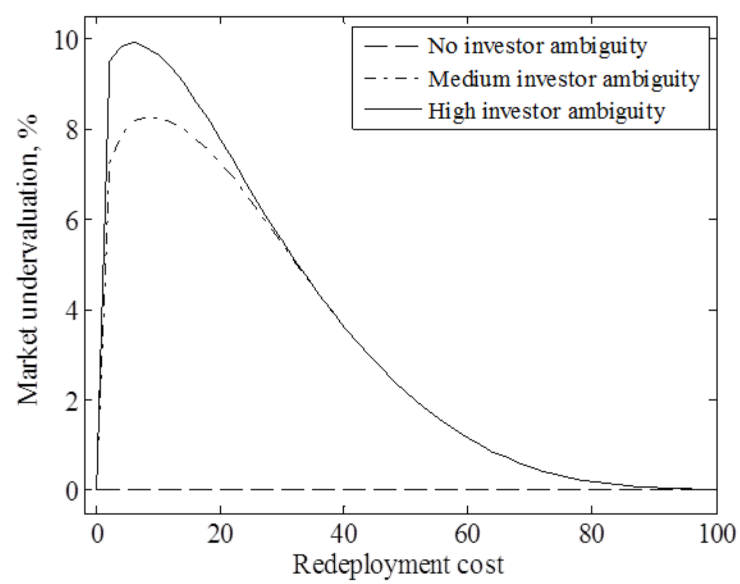
B. Effect of return correlation on market undervaluation

Figure 5. Value implications of return correlation

True resource value (V_0^R) is computed with Equation 5. Market undervaluation is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 7) from their true value (V_0^R) and scaling the difference by the true value (V_0^R). Return correlation is ρ in Equation 3. Investor ambiguity is volatility (σ_S) of investor beliefs about the marginal redeployment cost, taking zero $\sigma_S = 0$, medium $\sigma_S = 1$, and high $\sigma_S = 2$ values. Other parameters used for calculations include current market returns $C_{i0} = C_{j0} = 0.08$; return volatilities $\sigma_i = \sigma_j = 0.5$; marginal redeployment cost $S = 10$; risk-free interest rate $r = 0.08$; length of the resource lifecycle $T = 1$; number of time discretization steps $N = 200$; and the number of capacity discretization steps $L = 1$. Without loss of generality, the value of the originally invested resources I_0 is standardized to unity.



A. Effect of redeployment cost on true value



B. Effect of redeployment cost on market undervaluation

Figure 6. Value implications of redeployment cost

True resource value (V_0^R) is computed with Equation 5. Market undervaluation of resources is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 7) from their true value (V_0^R) and scaling the difference by the true value (V_0^R). Redeployment cost is measured with the marginal redeployment cost S. Investor ambiguity is volatility (σ_S) of investor beliefs about the marginal redeployment cost, taking zero $\sigma_S = 0$, medium $\sigma_S = 1$, and high $\sigma_S = 2$ values. Other parameters used for calculations include current market returns $C_{i0} = C_{j0} = 0.08$; return volatilities $\sigma_i = \sigma_j = 0.5$; return correlation $\rho = 0$; risk-free interest rate $r = 0.08$; length of the resource lifecycle $T = 1$; number of time discretization steps $N = 200$; and the number of capacity discretization steps $L = 1$. Without loss of generality, the value of the originally invested resources I_0 is standardized to unity.

ONLINE APPENDIX A: ROBUSTNESS OF RESULTS

Two types of robustness tests were performed. In the first series of tests, each of Figures 3, 4, 5, 6 was recreated while varying each determinant of redeployability fixed in the figure. Figure 6 was tested when (a) the current advantage was –50% ($C_{j0} = 0.040$), –20% ($C_{j0} = 0.064$), –10% ($C_{j0} = 0.072$), –5% ($C_{j0} = 0.076$), 5% ($C_{j0} = 0.084$), 10% ($C_{j0} = 0.088$), 15% ($C_{j0} = 0.092$), 20% ($C_{j0} = 0.096$), 50% ($C_{j0} = 0.120$), 100% ($C_{j0} = 0.160$), and 150% ($C_{j0} = 0.200$); (b) volatilities $\sigma_i = \sigma_j$ were 0.1, 0.2, 0.3, 0.4, 0.6, 0.7, 0.8, and 0.9; and (c) correlation ρ was –0.9, –0.6, –0.3, 0.3, 0.6, and 0.9. The relationships summarized with Hypotheses 5, 10, and 11 were confirmed with each of those alterations, even though the following ramifications emerged. With the rise of the current advantage from –50% to 150%, the peak undervaluation occurring with high ambiguity shifted from low redeployment costs $S = 2$ to high costs $S = 122$. With the departure of the current advantage from zero, the peak undervaluation became lower. In particular, with high ambiguity, the peak undervaluation dropped from 9.9% to 1.2% when the advantage was –50% and to 3.1% when the advantage was 150%. That drop corresponds to the inverted U-shaped relationship in Panel B of Figure 3. With the increase of return volatility from $\sigma_i = \sigma_j = 0.1$ to $\sigma_i = \sigma_j = 0.9$, the peak in the undervaluation occurring with high ambiguity moved from $S = 2$ to $S = 10$; the magnitude of the undervaluation grew from 2.2% to 15.8%. That rise in the height of the peak corresponds to the upward slope observed in Panel B of Figure 4. With the increase of return correlation from $\rho = -0.9$ to $\rho = 0.9$, the peak in the undervaluation occurring with high ambiguity migrated from $S = 8$ to $S = 2$; the height of the peak declined from 12.9% to 3.3%. That decrease in the magnitude corresponds to the downward slope in Panel B of Figure 5.

Figure 3 was recreated when (a) the marginal redeployment cost S was 5, 15, 20, 30, 40, 50, 60, 70, 80, 90 and 100; (b) volatilities $\sigma_i = \sigma_j$ were 0.1, 0.2, 0.3, 0.4, 0.6, 0.7, 0.8, and 0.9; and (c) correlation ρ was –0.9, –0.6, –0.3, 0.3, 0.6, and 0.9. The relationships summarized with Hypotheses 2, 6, and 7 were confirmed with each of those changes; although some ramifications occurred. With the rise of redeployment costs from $S = 5$ to $S = 100$, the peak undervaluation with high ambiguity shifted from zero current advantage to 100% advantage; the height of the peak declined from 10.0% to 5.4%. With the increase of return volatility from $\sigma_i = \sigma_j = 0.1$ to $\sigma_i = \sigma_j = 0.9$, the peak in the undervaluation with high ambiguity moved from zero advantage to 10% advantage; the magnitude of the undervaluation grew from 0.7% to 16.0%. That rise in the effect corresponds to the upward slopes in Panel B of Figure 4. With the rise of return correlation from $\rho = -0.9$ to $\rho = 0.9$, the peak in the undervaluation with high ambiguity moved from 10% advantage to zero advantage; the magnitude of the undervaluation dropped from 13.1% to 2.0%. The decline in the effect corresponds to the downward-slope relationship reported in Panel B of Figure 5.

Figure 4 was tested when (a) the marginal redeployment cost S was 5, 15, 20, 30, 40, 50, 60, 70, 80, 90 and 100; (b) the current advantage was –50%, –20%, –10%, –5%, 5%, 10%, 15%, 20%, 50%, 100%, and 150%; and (c) correlation ρ was –0.9, –0.6, –0.3, 0.3, 0.6, and 0.9. The relationships summarized with Hypotheses 3 and 8 were confirmed with each of those changes;

although the following specifics emerged. With the increase of redeployment costs from $S = 5$ to $S = 100$, the maximum undervaluation declined from 15.4% to 0.8%. With the departure of the current advantage from zero, the highest undervaluation occurring with high ambiguity dropped from 15.8% to 4.7% when the current advantage was –50% and to 2.8% when the advantage was 150%. That decrease matches the inverted U-shaped relationship in Panel B of Figure 3. With the increase of return correlation from $\rho = -0.9$ to $\rho = 0.9$, the maximum undervaluation with high investor ambiguity dropped from 19.4% to 4.9%. The decline in the effect complies with the decreasing relationship in Panel B of Figure 5.

Figure 5 was tested when (a) the marginal redeployment cost S was 5, 15, 20, 30, 40, 50, 60, 70, 80, 90 and 100; (b) the current advantage was –50%, –20%, –10%, –5%, 5%, 10%, 15%, 20%, 50%, 100%, and 150%; and (c) volatilities $\sigma_i = \sigma_j$ were 0.1, 0.2, 0.3, 0.4, 0.6, 0.7, 0.8, and 0.9. The results summarized with Hypotheses 4 and 9 were confirmed with each of those changes; although the following peculiarities occurred. With the increase of redeployment costs from $S = 5$ to $S = 100$, the maximum undervaluation dropped from 12.9% to 0.2%. With the departure of the current return advantage from zero, the highest undervaluation occurring in the presence of high ambiguity decreased from 13.0% to 2.3% when the current return advantage was –50% and to 1.2% when the current return advantage was 150%. That drop matches the inverted U-shaped relationship in Panel B of Figure 3. With the increase of return volatility from $\sigma_i = \sigma_j = 0.1$ to $\sigma_i = \sigma_j = 0.9$, the maximum undervaluation with high investor ambiguity increased from 1.6% to 19.6%. The increase fits with the upward slope in Panel B of Figure 4.

Although the first series of tests demonstrated the robustness of the relationships stated in the section 'Summary of theoretical results,' two issues are worth mentioning. First, there are two-way interactions between the determinants of redeployability and three-way interactions among those determinants and investor ambiguity. Second, the interaction between redeployment costs and the current return advantage, while not emphasized in the paper, is particularly interesting. Namely, with greater current return advantages, the peak undervaluation shifts to higher redeployment costs, or lower relatedness. In other words, it becomes more likely that stock market investors will not fully account for the value of redeploying resources to less-related (but better-performing) alternative business.

The second series of tests relaxed the restriction that the redeployment cost is the only source of ambiguity. When the new business starts by redeployment from the existing business (in which resources are evaluated), or redeployments from the existing business occur very soon after the emergence of the new business, ambiguity about returns in the new business may also be essential. Modeling such ambiguity is difficult. In contrast to redeployment costs S_t^I (for which the highest possible value S_t^{Iu} is the worst case with any C_{it} and C_{jt}), the worst case for ambiguous parameters $C_{j0}^I, \sigma_{j0}^I,$ and ρ^I of the new business would depend on realizations for C_{it} and C_{jt}. In that case, numerical tractability of Equation 7 can only be ensured by a simpler representation of priors for $C_{j0}^I, \sigma_{j0}^I,$ and ρ^I than is used for S_t^I in Equation 6. In particular, low ambiguity for C_{j0}^I is specified *via* three priors $C_{j0}^I = \{C_{j0} - 0.01, C_{j0}, C_{j0} + 0.01\}$ with relatively low variation; whereas high ambiguity for C_{j0}^I is specified as $C_{j0}^I = \{C_{j0} - 0.05, C_{j0}, C_{j0} + 0.05\}$

with relatively high variation. Low ambiguity for σ^I_{j0} is modeled as $\sigma^I_{j0} = \{\sigma_j - 0.1, \sigma_j, \sigma_j + 0.1\}$ with relatively low variation; whereas high ambiguity for σ^I_{j0} is specified by enabling $\sigma^I_{j0} = \{\sigma_j - 0.3, \sigma_j, \sigma_j + 0.3\}$ with relatively high variation (subject to the natural constraint $\sigma^I_{j0} \geq 0$). Finally, low ambiguity for ρ^I is specified as $\rho^I = \{\rho - 0.1, \rho, \rho + 0.1\}$ with relatively low variation; whereas high ambiguity for ρ^I is modeled as $\rho^I = \{\rho - 0.3, \rho, \rho + 0.3\}$ with relatively high variation (subject to the natural constraint $-1 \leq \rho^I \leq 1$). Each of Figures 3, 4, 5, 6 was recreated while keeping ambiguity about S intact and introducing low or high ambiguity about $C_{j0}, \sigma_j,$ or ρ. The results of all but two of these 24 tests (*i.e.*, 4 figures, 3 parameters relaxed, and 2 magnitudes of ambiguity for the relaxed parameter) reconfirmed Hypotheses 2–11. The first deviation occurred when Figure 6 was recreated with high ambiguity about the current return C_{j0} in the new business. In particular, the inverted U-shaped relationship between the stock market undervaluation of redeployability and redeployment costs transferred into the downward-slope relationship exactly repeating the relationship in Panel A of Figure 6. That extreme result emerged because the worst-case for ambiguous current returns C^I_{j0} in the new business was so bad that investors entirely disregarded redeployability, regardless of redeployment costs. The second deviation occurred in the very specific and rather unlikely case when Figure 5 was recreated with high ambiguity about return correlation ρ but no ambiguity about redeployment costs S. Thus, the monotonic negative relationship between stock market undervaluation and return correlation changed to the inverted U-shaped relationship.

ONLINE APPENDIX B: ILLUSTRATION OF STOCK MARKET UNDERVALUATION OF REDEPLOYABILITY

Stock market undervaluation of redeployability is illustrated here with data from Apple Inc. (hereinafter Apple). Three features make Apple an appropriate case. First, with its great publicity, Apple is an apt constituent of the efficient stock market, where information available to market players is promptly reflected in the firm's stock price. Specifically, as a global leader in information and communication technology, maintaining the most valuable brands, Apple is at the focus of mass media. Besides, the firm is closely followed by dozens of analysts who regularly factor news about Apple into estimates for its stock price. Second, Apple recently exercised very impactful resource redeployment. On January 9, 2007, Steve Jobs introduced the iPhone and changed the firm's name from Apple Computer Inc. to Apple Inc., highlighting the shift from computers to smartphones. By 2013, the role of smartphones in Apple's sales rose to 53.4%, boosting sales to $170.9 billion (*cf*. $6.2 billion in 1991) and margins to 22.2% (*cf*. 6.9% in 1991). Finally, the trend for Apple's stock price depicted in Figure B1 contains a pattern that can reflect the undervaluation of redeployability. Notably, after having stayed flat and underperformed the NASDAQ index for the first decade in Figure B1, the stock price suddenly increased by a factor of 38 over the last decade. Three possible explanations for that pattern are considered in turn below.

Insert Figure B1 here

Consistent valuation in an efficient market

In the efficient market, a hike in a firm's valuation should reflect the arrival of new, significant, and positive information about the firm. Therefore, the ability of market efficiency to explain Figure B1 is tested by comparing the timing of the sharp change in Apple's stock price with the timing and the significance of good news about the firm. With the rise of the iPhone, from generating no revenue for Apple before 2007 to overtaking computers in the firm's operating performance in 2013, a sizable part of the hike in the stock price in Figure B1 is due to redeployment of resources from computers to smartphones. Leaving aside the generic drop during the 2008 financial crisis, the steepest change in Apple's value indeed occurred in 2007, when the iPhone was released. The stock price jumped by 13% on the day after the January 9, 2007 launch, reaching a previously unequalled peak and beginning the increase in Apple's valuation. What was so surprising, substantive, and positive in the iPhone announcement *per se*? Alternatively, had there been no significant good news about redeployability before January 9, 2007? The following substantive and positive information, which was known to investors long before the iPhone introduction, but was not evident in the flat trend for Apple's stock market price, challenges the relevance of market efficiency for the case under consideration.

- The reality of redeployability from computers to smartphones was first revealed to stock market investors in early 1990s, when Apple's computers were repeatedly compared to smartphones in their functionality (*New York Times*, 1993; *USA Today*, 1992). In 1992, another computer firm, IBM Corporation reallocated resources to smartphones and released the prototype Angler, followed by the smartphone Simon. Although IBM Corporation quickly exited the smartphone business, the same move was very successfully replicated by HTC Corporation, which had also originally been a computer firm. After the launch of its first smartphone, the HTC Wallaby, HTC Corporation reduced its reliance on computers so that they accounted for only one third of its revenue by the end of 2003. With that redeployment, the firm's net margin steadily grew, from 6.19% in 2001, to 7.10% in 2002, to 8.5% in 2003 (a total rise of 37% above the 2001 level). In the efficient market, investors estimating expected utility should have factored in a nontrivial probability of comparable positive results, and increased Apple's stock price based on the observed achievements of HTC Corporation.

- Apple's commitment to redeployability had been observed by investors since early 1990s. Apple allied with Siemens to combine computers with phones (*InfoWorld*, 1993) and built standards for mobile communication (*Business Wire*, 1997). In 1999, Apple bought the domain 'www.iphone.org' for its smartphone. By 2004, Apple had registered the trademark 'iPhone' in the UK, Singapore, Australia, and Canada. If a costly commitment signals an agent's superior capability (Spence, 1973), the actual investment Apple had made in redeployability before 2007 was an even more credible signal to investors than just the iPhone announcement.
- Inducements for redeploying resources from computers to smartphones were strong beginning in 2000. According to regularly released research, computer sales had declined, margins had shrunk, and Apple faced inventory buildups. Reflecting the trend, reports from Gartner Inc. were titled "U.S. PC market moves into negative territory" (April 20, 2001), "Worldwide PC market growth negative for first time since 1986" (July 20, 2001), and "U.S. and worldwide PC markets contract sharply in 3Q01" (October 17, 2001). Concurrently, researchers touted a boom in smartphones. In 2000, the number of smartphones in the United States was predicted to grow to 80 million by 2003 (*Presstime*, 2000). Annual smartphone sales in the United States were predicted to increase from $867 million in 2000 to $7.8 billion in 2005 (*PR Newswire*, 2000). Assessing HTC Corporation on March 20, 2002, Credit Suisse expected that smartphone shipments would grow by 158% per year from 2001 to 2005. In the efficient stock market, investors assessing expected utility would have started counting on the strong upside potential for computer firms in smartphones in early 2000s, rather than would have waited until 2007.

The delayed response of Apple's stock price to all of that new, significant, and positive information can be further illustrated by a review of how redeployability featured into stock analysts' price estimates of for Apple.[1] Around the time of the iPhone release, Apple was being followed by 15 analysts, whose reports are available in the Thompson One and Morningstar databases.[2] Before 2007, seven analysts had never mentioned iPhone; five had mentioned iPhone but did not take it into account in their estimates; two had started factoring in the iPhone one month before its release, by only slightly adjusting upward the estimates for Apple; and one analyst had started his coverage of Apple just one month before the iPhone release and cautiously added iPhone to the estimate.[3] For instance, ThinkEquity, while acknowledging the

[1] Analysts not only monitor investor behavior but also significantly affect stock prices (Francis and Soffer, 1997; Stickel, 1991).
[2] Those analysts were Caris&Company, Credit Suisse, Deutsche Bank, JPMorgan, Kintisheff Research, Morningstar, Morgan Stanley, NewConstructs, PiperJaffray, Prudential Equity, RapidRatings, R.L.Renck&Co., ThinkEquity, ValueEngine, and UBS.
[3] The analysts who had not mentioned iPhone before its official announcement were Credit Suisse, Kintisheff Research, Morningstar, NewConstructs, RapidRatings, R.L.Renck&Co., and ValueEngine. The analysts who had been confident that Apple would launch iPhone in early 2007 but who had excluded cash flows from iPhone from their estimates for Apple before January 9, 2007 were Deutsche Bank, JPMorgan, PiperJaffray, ThinkEquity, and UBS. The analysts who had started very cautiously counting on iPhone one month before its introduction were Caris&Company, Morgan Stanley, and Prudential Equity.

upside potential for Apple due to iPhone, explicitly stated that the report of October 19, 2006 excludes that potential from the offered valuation for Apple:

> All the speculation around an iPhone… should materialize and further boost Apple's BtB [Beyond the Box] ecosystem. For the record, *we have not baked any revenue or earnings contributions from… iPhones… into our model* [emphasis added].

Similarly, UBS stated in the report of December 12, 2006:

> We currently do not have cell phones or related services in our model… While not in our model, it is becoming more important to quantify the cell phone opportunity.

In addition to stating that they excluded iPhone from their valuations for Apple, some analysts assessed that redeployability of Apple's resources to smartphones had not been fully factored into Apple's market price before 2007. Thus, JPMorgan reported on August 4, 2006:

> There have been recent rumblings in the Apple news community that the company may surprise everyone with a branded cell phone launch... *We don't believe investors have put much credibility in the chatter* [emphasis added] …we believe the eventual launch will be seen as a significant positive catalyst when it does occur, and this is *not yet factored into our already above consensus 2007 estimates* [emphasis added].

Similarly, PiperJaffray noted in its report of August 2006:

> …the iPhone will be the next major growth driver in the Apple story. Currently, *the* [Wall] *Street models do not reflect the iPhone contribution* [emphasis added].

The apparent exclusion of the iPhone contribution from Apple's valuation before 2007 contrasts with the early availability of the new, significant, and positive information about redeployability of Apple's resources to smartphones and therefore limits the applicability of market efficiency to the case. Relaxing the requirement for market efficiency invites two alternative interpretations.

Later overvaluation

If the assumption of market efficiency is relaxed, one likely explanation for Figure B1 is that Apple's stock grew increasingly overvalued since 2007. Investors may have become too optimistic about Apple after the iPhone release. Such overvaluation is usually revealed in the following empirical patterns. First, ordinarily the number of the firm's shares sold by insiders (*i.e*., officers, directors, and large shareholders) should go up, reflecting the insiders' private view that the true value of the firm's resources is below their market value (Seyhun, 1992). To check that scenario, Figure B2 displays the portion of Apple's equity sold by insiders per month in 2003–2013. The figure indicates that sales of Apple's stock by insiders robustly declined to a negligible level in 2013. While unable to fully negate the possibility that Apple's stock was overpriced in 2013, the trend contradicts the idea that the spike in Apple's value after 2007 was due to rising overvaluation. Second, with growing overvaluation, the number of the firm's shares that are sold short (*i.e*., without owing them) should go up. In such deals, short-sellers hope to profit by selling overvalued shares that can be bought at a lower price later, when they should be delivered to buyers (Dechow *et al*., 2001). To test that scenario, Figure B3 shows the trend in the portion of Apple's equity sold short. The short-selling of Apple's stock significantly declined in the period under consideration. Hence, that measure of overvaluation negates the hypothesis that the hike in Apple's stock price was due to growing overvaluation. Third, assuming that stock analysts are diligent and less prone to investors' sentiments, a rising overvaluation should decrease the proclivity of analysts to recommend buying the stock. Figure B4 depicts the trends in the mean analyst recommendation for Apple (Panel A) and for the portion of analysts recommending that investors buy Apple (Panel B). The two trends can be cautiously interpreted as contradicting an increase in the overvaluation of Apple. Finally, with overvaluation the firm's book-to-market ratio should go down, representing declining opportunities for advance investors to buy the undervalued stock in anticipation of high future returns (Dechow *et al*., 2001). Figure B5 shows that, after the iPhone introduction, Apple's book-to-market ratio tended to grow, reflecting an increasing undervaluation or a decreasing overvaluation. Overall, the usual methods of diagnosing overvaluation of a stock generate evidence that runs counter to the hypothesis that Apple's stock was progressively more overvalued after 2007.

Insert Figures B2, B3, B4, and B5 here

Earlier undervaluation

Another interpretation of Figure B1, possible when the assumption of the market efficiency is relaxed, is that Apple's stock had long been undervalued, approaching its true value only by 2013. That explanation corresponds to the ideas, regarding the origin and the implications of ambiguity, reviewed in this study.

Origin of ambiguity

In line with the ideas about the origin of ambiguity (Bernstein, 1996; Ellsberg, 1961; Frisch and Baron, 1988), prior to the 2007 iPhone launch, resource redeployment from computers to smartphones remained a rare event, for which the data on outcomes were too patchy to be summarized with a probability distribution. Indeed Simon, launched by IBM Corporation in 1994, was a short-lived product that did not result in a representative record for outcomes. Among later smartphone releases by BlackBerry Limited, Ericsson Mobile Communications AB, HTC Corporation, Kyocera Corporation, Motorola Inc., Nokia Group, and Samsung Electronics Limited, the only case of resource redeployment from computers by 2007 had been HTC Corporation. Moreover, the cost of redeploying Apple's resources to smartphones was the determinant of redeployability least available to investors. Notably, while (as described above) investors had access to quantitative forecasts of the inducements for redeploying resources from computers to smartphones beginning in 2000, redeployment costs remained ambiguous even after January 9, 2007. Market players expressed several concerns about the costs Apple would incur to repurpose its resources for smartphones, but they could not quantify such costs.

The first type of ambiguous redeployment costs, which emerged in the adjustment of the distribution system, was mentioned by Caris & Company in the report of December 7, 2006:

> [Apple] will have to make a difficult decision about how to sell such a product [iPhone]. It can have the wireless service providers sell this product, but the WSPs may insist that Apple modify its product by incorporating the brand of the WSP or by some other modification. If Apple decides to run its own "virtual" service, then it will become partly a service company. This would be disruptive to the current business model.

Similarly, UBS highlighted in its report of December 12, 2006:

> Apple currently has approximately 174 stores in the U.S. and abroad, which pales in comparison to national carriers. For example, Verizon has 2,100 direct stores, Cingular has 2,100 and T-Mobile has 1,200. Given that stores are an integral part of the wireless offering as subscribers visit stores to fix or upgrade handsets and often to pay bills, Apple's relatively small presence may be a challenge.

A second concern was whether Apple's engineers could tailor technical features from Apple's other devices to the iPhone. For example, the limited ability of batteries to last long enough to support smartphone functions was mentioned in 2007 by Caris & Company, Credit Suisse, Prudential Equity, RBC Capital Markets, PiperJaffray, and UBS. Analysts also worried about the vulnerability of iPhone screens to scratching. A third type of uncertain redeployment costs, highlighted by Credit Suisse, Deutsche Bank, JPMorgan, Morgan Stanley, PiperJaffray, Prudential Equity, ThinkEquity, and UBS, was the need to withdraw programmers from other units to develop the special software for the iPhone. Naturally, ambiguity about these costs incurred by Apple in redeploying its resources from computers to smartphones declined from 2007 to 2013, as sufficient evidence accumulated regarding Apple's performance in smartphones.

Implication of ambiguity

Consistent with the idea that the key implication of ambiguity is ambiguity aversion (Ellsberg, 1961), Apple's case comprises two signs of such aversion: the failure to respond to good news about the firm by investors facing ambiguity (Williams, 2015) and the tendency for investors to hedge against ambiguity by considering the worst-case scenario (Drechsler, 2013). The lack of attention to the good news about Apple, listed in section 'Consistent valuation in efficient market,' was reflected in the stagnation of Apple's stock price before 2004. The tendency of market participants to count on the worst-case scenario was manifested in the conservative estimates for Apple developed by analysts. Thus, although resource redeployability from computers to smartphones had been demonstrated in 1994 by IBM Corporation and reaffirmed by HTC Corporation in 2002, most analyst estimates for Apple had assigned zero (*i.e*., the worst) value to that option prior to the actual iPhone launch. Even after the launch, analysts were cautious about the margin Apple would earn with iPhone. For example, evaluating Apple on January 10, 2007, Credit Suisse estimated a net margin of 10% on iPhone, far below both the net margin of 14% that Apple had earned previously and the net margin of 15% that Nokia Group and Motorola Inc. had already earned on smartphones. Of course, faced with rising iPhone margins after 2007 (*i.e*., the resolution of ambiguity), market analysts revised upward the margin used in their estimates for Apple's value.

Although the latency of a firm's true value makes incontrovertible evidence of market undervaluation impossible, the facts about Apple presented here appear to fit the interpretation that redeployability of Apple's resources had long been undervalued due to ambiguity, rather than the two alternative explanations for the pattern observed in Figure B1.[4]

[4] Another interpretation for the undervaluation of Apple may be a downward bias in the valuation of redeployability by stock investors due to the unsuccessful resource redeployment from computers to smartphones observed in the case of IBM Corporation. That interpretation, while feasible, does not appear to be stronger than the interpretation based on ambiguity. The arrival of data about the very strong upside potential in early 2000s should have reduced the downward bias. However, until the iPhone announcement, stock analysts and investors had relied on the worst-case, rather than just unfavorable, scenario. Consistent with the worst–case scenario for the real option, the value of redeployability had been considered zero, rather than reduced by some amount.

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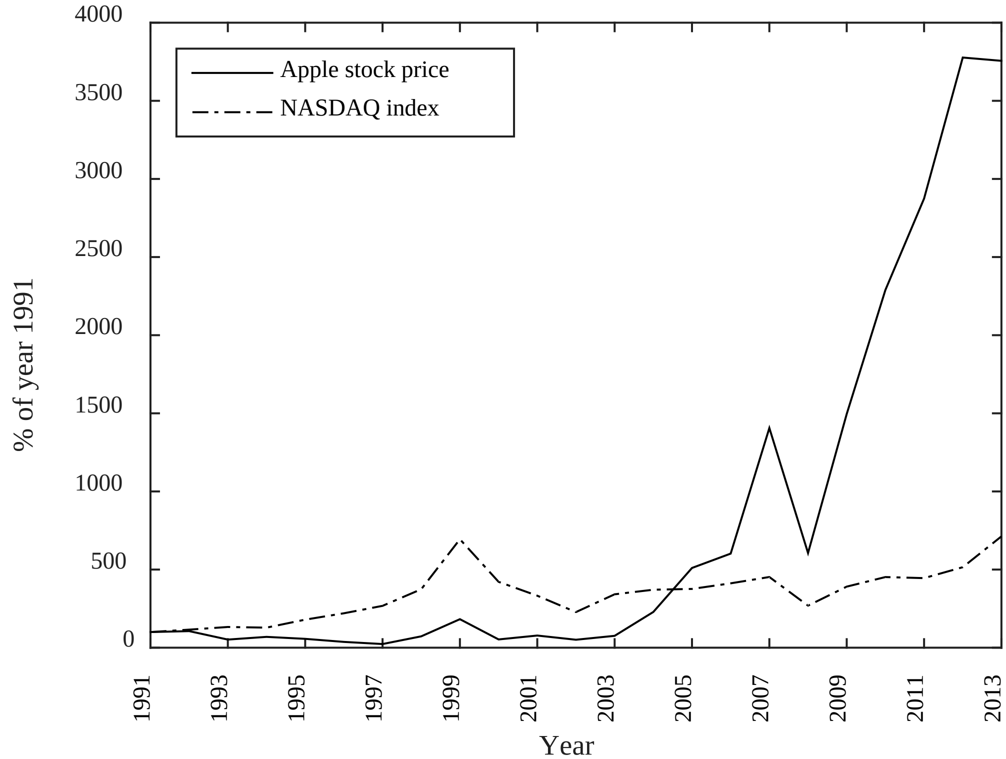


Figure B1. Dynamics of stock price of Apple Inc.

The NASDAQ index and stock prices of Apple Inc. on the last day of a year are taken from the US stock database of the Center for Research in Security Prices (CRSP). The data are scaled by the values in year 1991.

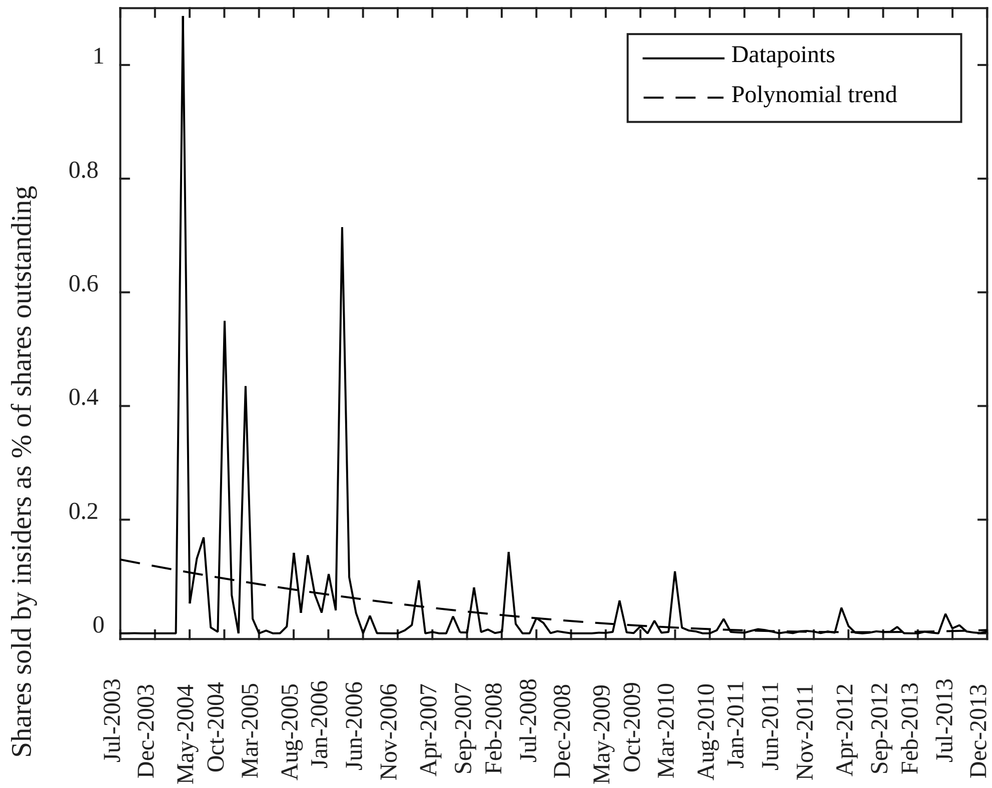


Figure B2. Intensity of insider trading of Apple Inc.

The number of shares of Apple Inc.sold by insiders is taken from Table 1 of the Thomson Reuters Insider Filing dataset. The data are aggregated in each months. The number of shares outstanding of Apple Inc.on the last day of a month are taken from the US stock database of the Center for Research in Security Prices (CRSP). The polynomial trend represents the second-order polynomial fitting line.

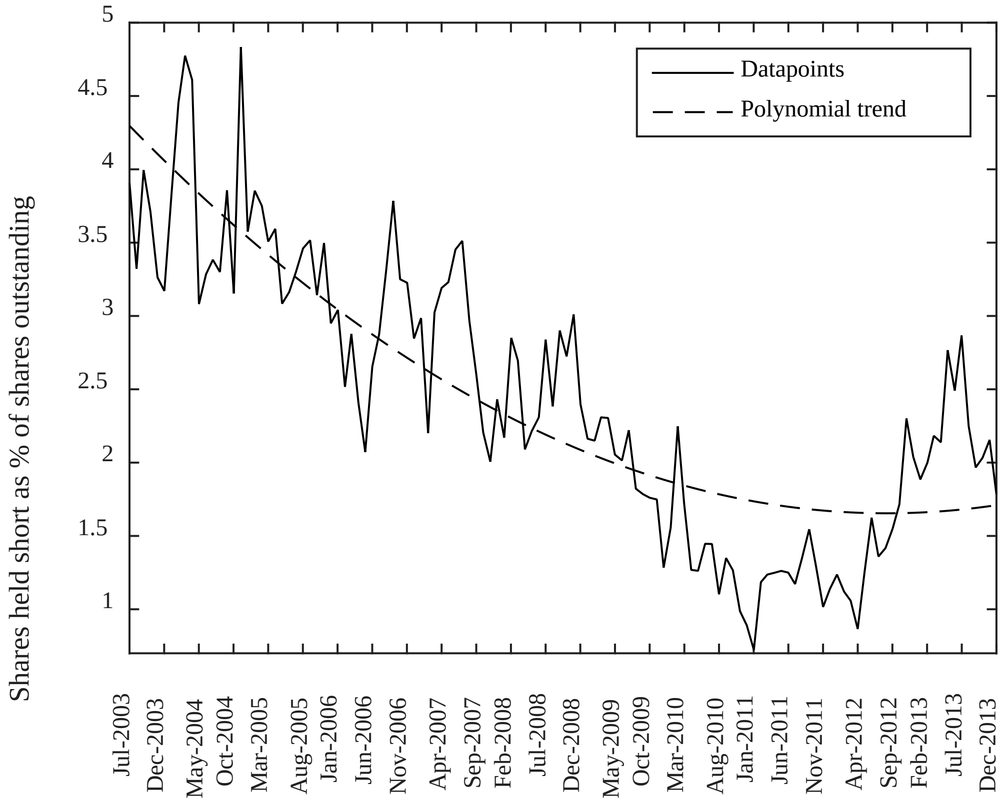
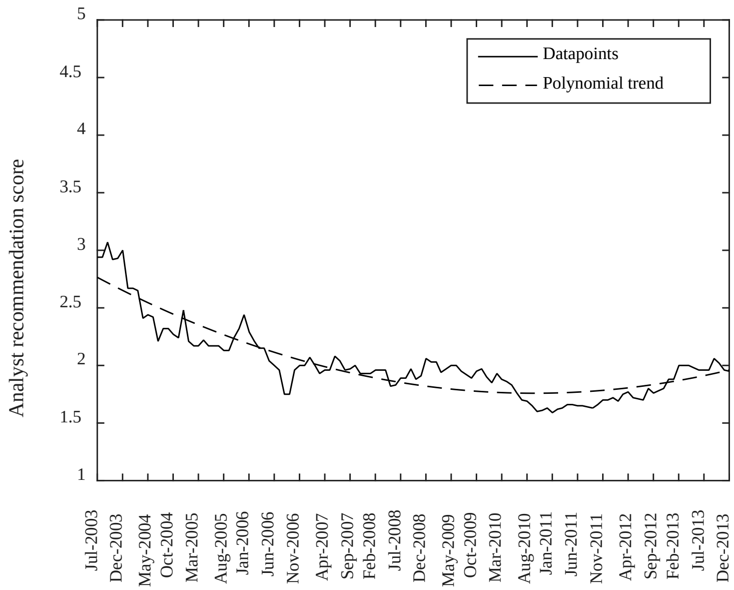
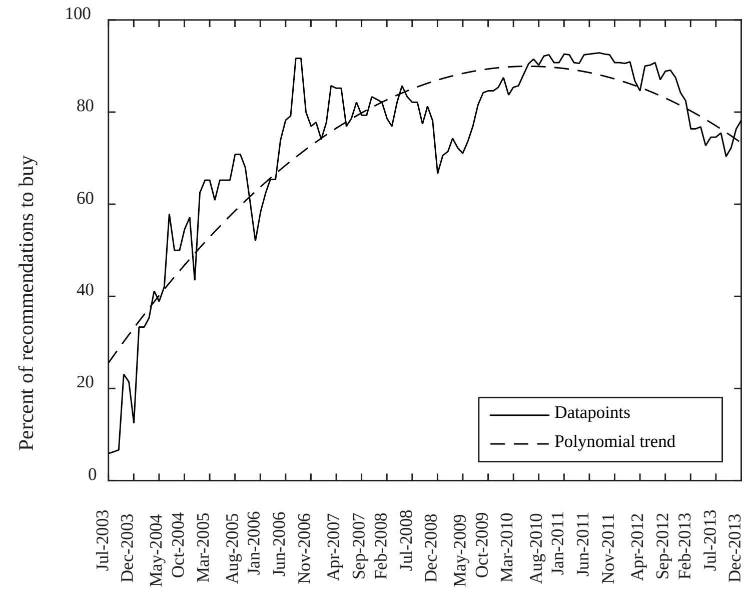


Figure B3. Intensity of short-selling of Apple Inc.

The number of shares of Apple Inc.held short is taken from the Supplemental Short Interest File of the Wharton Research Data Services (WRDS) Compustat-Capital IQ dataset. The data are aggregated in each month. The number of shares outstanding of Apple Inc. on the last day of a month are taken from the US stock database of the Center for Research in Security Prices (CRSP). The polynomial trend represents the second-order polynomial fitting line.



C. Effect of current return advantage on true value



D. Effect of current return advantage on market undervaluation

Figure B4. Summary of recommendations of stock market analysts for Apple Inc.

The data on analyst recommendations for the stock of Apple Inc.are taken from from the Thomson Reuters I/B/E/S database and corresond to the middle of each month. In Panel A, the scale for recommendations is the following: '1' is 'Strong Buy'; '2' is 'Buy'; '3' is 'Hold'; '4' is 'Underperform'; and '5'is 'Sell.' In Panel B, percent of recommendations to buy include both 'Strong Buy' and 'Buy.' The polynomial trend represents the second-order polynomial fitting line.

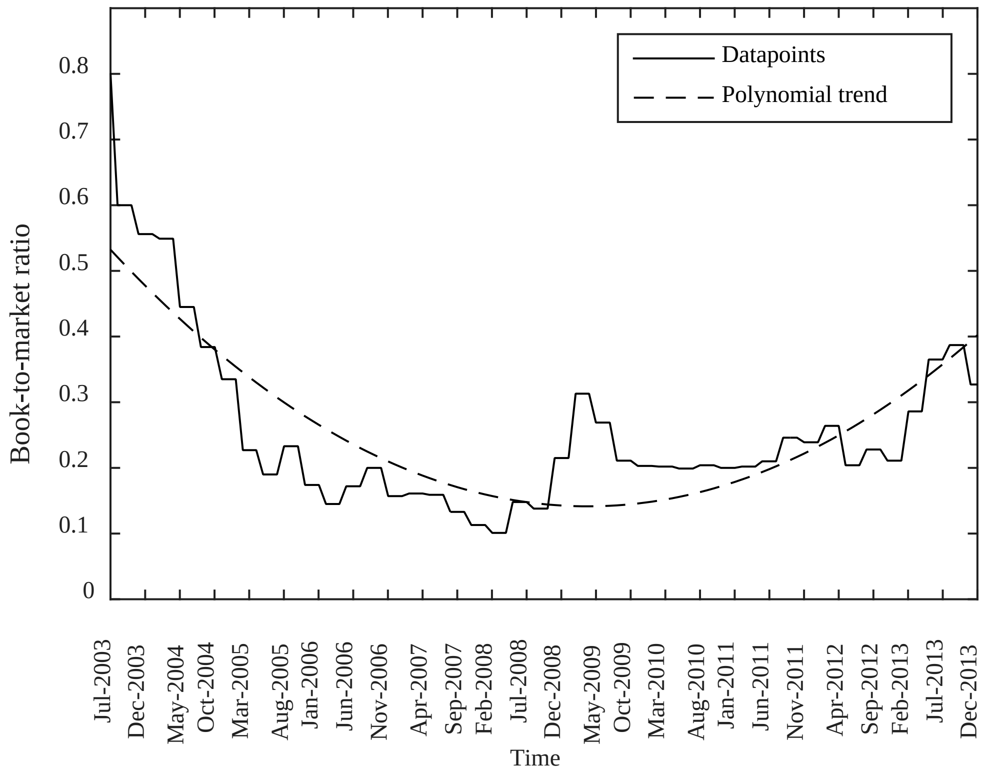


Figure B5. Book-to-market ratio of Apple Inc.

The book-to-market ratio of Apple Inc. on the last day of a month is taken from the Wharton Research Data Services (WRDS) Industry Financial Ratio dataset. The polynomial trend represents the second-order polynomial fitting line.