STOCK MARKET UNDERVALUATION OF RESOURCE REDEPLOYABILITY

Arkadiy V. Sakhartov
The Wharton School
University of Pennsylvania
2017 Steinberg Hall–Dietrich Hall
3620 Locust Walk
Philadelphia, PA 19104–6370
Phone (215) 746 2047
Fax (215) 898 0401
arkadiys@wharton.upenn.edu

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ABSTRACT

The study extends applicability of the strategic factor market theory to acquisitions of resources in the market for companies, contrasting with the view that efficiency of stock markets precludes strategizing in those markets. The field example illustrates that one aspect of firms' resources, their redeployability to new product markets, can be persistently underpriced by market investors. Furthermore, the simulation model demonstrates that the undervaluation can be predicted, specifying the undervaluation as a function of the observable resource properties. The model illuminates the redeployability paradox — the same factors, making resources objectively more–valuable, can also make them more–undervalued in the stock market. The derived operationalization of the undervaluation is useful for empiricists testing implications of the strategic factor market theory and managers seeking for sources of abnormal returns.

Keywords: strategic factor markets; resource acquisition; resource redeployment; real options; simulation method.

INTRODUCTION

A key insight of the strategic factor market theory is that firms earn above–normal returns, when acquiring resources at prices below the true value those resources have in implementing product market strategies (Barney, 1986). The excess returns are realized through (a) 'luck' (Barney, 1986) when firms happened to buy underpriced resources; (b) 'serendipity' (Denrell, Fang, and Winter, 2003) when firms discover the true value of resources after trying them in alternative uses; or (c) 'strategic factor market intelligence' (Makadok and Barney, 2001) when firms deliberately collected, filtered, and interpreted information about the resource value before the resource acquisition. While disagreeing on the extent of rationality involved in the discovery of strategic opportunities, the three explanations share the assumption that the abnormal returns demand the *market undervaluation* of the resources.

The potential for strategizing around the undervaluation in strategic factor markets is particularly intriguing when applied to the contexts where firms buy stock of other firms containing the targeted resources. Although Barney (1986: 1232) asserted that 'the market for companies is a strategic factor market,' there are compelling theoretical reasons to expect that strategizing around resources mispriced in stock markets is precluded by market efficiency:

> …we view markets as amazingly successful devices for reflecting new information rapidly and… accurately …we believe that financial markets are efficient because they don't allow investors to earn above–average risk adjusted returns… Before the fact, there is no way in which investors can reliably exploit any anomalies or patterns that might exist. I am skeptical that any of the 'predictable patterns'…were ever sufficiently robust so as to have created profitable investment opportunities. (Malkiel, 2003: 60–61)

The efficiency of modern financial markets is believed to be enabled by mass media coverage of traded firms and a careful audit of the value of those firms by market analysts and institutional investors. Despite the apparent controversy, existing strategy research has not scrutinized the potential to exploit the resource undervaluation in stock markets. In particular, formal models (Adegbesan, 2009; Makadok and Barney, 2001; Maritan and Florence, 2008) were restricted to the game played by a handful of firms, who directly engaged in resource deployment strategies and bargained over the resource prices. Those models could not capture the behavior of diffuse market investors, distant from actual resource deployment yet setting prices for firms' resources in the stock market. Furthermore, the extant analytical models, as well as emergent empirical research on strategic factor markets (Capron and Shen, 2007; Coff, 1999; Laamanen, 2007), focused on the *ex post* implications of the assumed mispricing but did not enable to predict the resource undervaluation *per se*. Thus, the question of whether the insights of the strategic factor market theory apply to stock markets has remained largely unresolved.

To predict the stock market undervaluation of resources, the present paper develops a simulation model.[1] The model builds on three qualitative insights. First, the model sticks to the idea that the market undervaluation of a resource is the difference between its 'true value' and the 'pessimistic expectation' of that value held by market participants facing ambiguity about the resource value (Barney, 1986: 1234).[2] To incorporate that idea, the model applies a technique of asset valuation in incomplete markets where investors face ambiguity about the asset's value and price the asset based on the most pessimistic scenario (Riedel, 2009). Second, the model uses the insight of Maritan and Florence (2008: 228–229) that resources have a real option property, which enables their redeployment to new product markets but is most amenable to mispricing.[3] To apply the second insight, the model evaluates resource *redeployability* — the real option to

[1] Davis, Eisenhardt, and Bingham (2007: 481) define simulation as 'a method for using computer software to model the operation of "real–world" processes, systems, or events.'

[2] In addition to the undervaluation scenario, resources may be overvalued (Barney, 1986: 1233–1234). In that case, optimistic buyers pay for the resources a price above the true future value of the resources. Such participants incur economic losses in the long run and are unlikely to be viable representatives of the market.

[3] Market participants may also face ambiguity about complimentarity of the traded resources with other resources possessed by firms (Adegbesan, 2009; Denrell *et al*., 2003). The present study does not consider mispricing of complimentarity.

withdraw the resources from their current use and reallocate them to an alternative product market. Third, the model uses the clarification of Denrell *et al*. (2003: 982) that the main reason for the mispricing in strategic factor markets is ambiguity faced by market participants about applicability of firms' resources in new uses. Such ambiguity is modeled as variability of market investors' beliefs about costs of redeploying the resources to the new product markets. The used simulation method overcomes challenges of qualitative reasoning (Ghemawat and Cassiman, 2007: 530) and analytical intractability (Broadie and Detemple, 2004: 1163) present when resources redeployments can be enacted at any time and involve some costs. Moreover, using simulation to theoretically specify the resource undervaluation in stock markets is a rational preliminary step before empirically testing the underdeveloped theory.

The model confirms that the resource undervaluation can be predicted, despite the alleged stock market efficiency. Beyond confirming generalizability of the strategic factor market theory to corporate acquisitions, the model delivers a specific operationalization of the resource undervaluation. The operationalization represents primary incentives for firms to strategize in markets for resources and can be used in empirical tests of firms' behavior in those markets. The received operationalization may also be used by managers to identify contexts where shopping for resources *via* corporate acquisitions adds most value. Presence of the resource undervaluation in the stock market and parameters used to predict it are discussed in the section right below.

RESOURCE UNDERVALUATION AND RESOURCE REDEPLOYABILITY

Example of market undervaluation of redeployable resources

The stock market valuation of firms' resources is considered with the example of Apple Inc. (hereinafter Apple). Apple is at the focus of mass media and market investors. The firm is a global leader in the information and communication technology and the most admired company in the world.[4] Apple leads the ranking of the most valuable brands.[5] In addition, Apple's stock is under close scrutiny. Institutional investors keep over 60 percent of Apple's equity.[6] The firm's stock is followed by dozens of analysts from primer institutions.[7] Given the amount of attention to Apple, the firm is one of the best possible constituents of the assumed efficient stock market. In such a market, if any news leads to a surge in Apple's stock price, that news should be a complete surprise to market participants. Apple's history contains an event when a surge in the stock price cannot be explained with investors' surprise about the firm's resources.

The studied event is redeployment of Apple's resources from computers to smartphones announced on January 9, 2007, when Steve Jobs presented iPhone and changed the firm's name from Apple Computers Inc. to Apple Inc.[8] Next day, Apple's stock price rose by 13 percent and reached $97.80, an all–time peak by that time. When Apple launched iPhone on June 29, 2007, the stock price grew to $124.00.[9] To present the market appreciation of the entry in smartphones, Figure 1 shows the historical stock prices of Apple in years between 1980 (when smartphones did not exist) and 2012 (when more than half of Apple's revenue came from iPhone). In that period, Apple' stock price grew from $4.27 to $532.17, or 125 times. As evident from the trend of the NASDAQ index, the price surge was not due to the macroeconomic trends and, in the efficient market, can only be explained if investors got surprised about the true value of Apple's resources in the growing smartphone business. Below are some facts consistent with the idea that a surge in Apple's stock was due to a systematic undervaluation rather than a market surprise.

[4] http://money.cnn.com/magazines/fortune/most-admired/2012/snapshots/670.html?iid=splwinners.
[5] http://www.nytimes.com/2013/09/30/business/media/apple-passes-coca-cola-as-most-valuable-brand.html?_r=2&.
[6] http://www.nasdaq.com/symbol/aapl/institutional-holdings.
[7] http://tech.fortune.cnn.com/2013/10/29/apple-best-worst-analysts.
[8] http://www.apple.com/pr/library/2007/01/09Apple-Reinvents-the-Phone-with-iPhone.html.
[9] http://www.apple.com/pr/library/2007/06/28iPhone-Premieres-This-Friday-Night-at-Apple-Retail-Stores.html.

Insert Figure 1 here

Was the market surprised that a computer firm can redeploy resources to smartphones? The answer to that question is negative. Investors should not have been surprised about such redeployability, because the option had been revealed to the market 15 years before iPhone. In particular, in 1992, the computer equipment company IBM redeployed part of its resources to smartphones and released prototype Angler, followed by smartphone Simon in 1994.[10] Such redeployment of resources to smartphones was replicated by other computer equipment firms (Palm Kyocera 6035 in 2001, HTC Wallaby in 2002, and HP iPaq h6315 in 2004).[11,12,13]

Was the stock market surprised with the rise of the consumer market for smartphones? Disconfirming that conjecture, smartphones had begun to prosper long before iPhone. In 1992, global annual sales of new telecommunication devices (including smartphones) were predicted to hit a trillion U.S. dollars by year 2000 (The Washington Post, 1992). In 2000, the number of smartphones in the U.S. was said to grow to 80.0 million by 2003, outplacing all other mobile Internet devices (Presstime, 2000). Sales of smartphones in the U.S. were forecasted to rapidly grow from $867 million in 2000 to $7.8 billion in 2005, corresponding to 60 million units (PR Newswire, 2000). Also, shipments of mobile devices, including smartphones, were projected to surpass shipments of computer notebooks by the end of 2002 (Business Wire, 1999).

Were stock market investors surprised that specifically Apple entered into smartphones? That surprise was unlikely. Thus, in early 1990s, Apple's portable computers were compared to smartphones (USA Today, 1992; The New York Times, 1993). Exploiting that adjacency, Apple allied with Siemens to combine computers with telephones (InfoWorld, 1993). In 1997, Apple

[10] http://www.businessweek.com/articles/2012-06-29/before-iphone-and-android-came-simon-the-first-smartphone.
[11] http://www.palminfocenter.com/view_story.asp?ID=1707.
[12] http://pocketnow.com/thought/a-look-at-the-first-htc-phone-ever-released.
[13] http://pocketnow.com/review/hp-ipaq-h6315-pocket-pc-phone-edition.

was developing standards for mobile communication (Business Wire, 1997). In 1999, the firm acquired domain 'www.iphone.org' for its smartphone.[14] In 2002, Apple's plan for iPhone was highlighted in mass media (Toronto Star, 2002; The New York Times, 2002). By 2004, Apple had applied for the trademark 'iPhone' in the U.K., Singapore, Australia, and Canada.[15,16] In November 2006, Apple was already expected to ship 12 million units of iPhone in early 2007.[17]

Was the increase in Apple's stock price a case of an overvaluation growing since 2007? If market efficiency is discarded, a growing overvaluation is plausible. However, that scenario confronts how redeployability had featured in analyst reports prior to January 9, 2007.[18] Because redeployability is an option but not an obligation, it may only add value. Therefore, cases where redeployability is not fully counted represent instances of undervaluation. Analyses of Apple prepared long before January 9, 2007 did not count possible revenues from iPhone.[19] Right before January 9, 2007, only few analysts mentioned redeployability of Apple's resources to smartphones but were rather conservative in valuation. For example, JPMorgan acknowledged that iPhone would be a new and important source of Apple's revenue but not counted on such revenues and left them an upside potential to the stock estimate (Shope and Borbolla, 2007).

Thus, before the release of iPhone, investors had known about redeployability of Apple's resources to smartphones, but had underpriced that option. Despite the boom in smartphones, Apple's stock price was flat and underperformed NASDAQ until 2004. Market analysts had also been reluctant to add redeployability to Apple's valuation until 2007. Consistent with the idea

[14] http://www.fiercewireless.com/story/timeline-apple-iphone-rumors-1999-present.
[15] http://www.macrumors.com/2002/12/03/apple-also-registers-iphone-trademark-in-uk.
[16] http://www.macrumors.com/2002/12/03/apple-registers-iphone-trademark
[17] http://money.cnn.com/2006/11/15/technology/apple_phone/?postversion=2006111511.
[18] Market investors extensively rely on forecasts of market analysts (Francis and Soffer, 1997; Stickel, 1991).
[19] For instance, JPMorgan corrected upward their estimate for Apple's stock, explaining: 'Our upward revenue and margin revisions are primarily focused on the iPod division, though we suspect our Mac forecasts may prove conservative as we complete our checks in December' (Shope and Borbolla, 2005). Another example is an upward update to Apple's valuation estimate introduced by Morningstar, describing: 'We're raising our fair value estimate for Apple to $66 per share from $60 to reflect modest assumption changes… We expect revenue will be driven by Macintosh and iPod/iTunes sales.' (Bare, 2006)

that redeployability of resources to smartphones was undervalued, Apple's stock price strongly depended on such predictors of value of staying in the *current* businesses as the accounting value of assets (correlation 0.90) and sales of the *existing* products (correlation 0.77).[20]

Predictors of resource undervaluation

A critical issue is whether the illustrated undervaluation can be predicted. Based on the idea that redeployability distorts market efficiency most (Maritan and Florence, 2008), a reasonable guess is that determinants of redeployability make resources more–valuable but more–undervalued. The resulting *redeployability paradox* is akin to the 'uniqueness paradox' (Litov, Moreton, and Zenger, 2012), whereby complex strategies are valuable but undervalued by investors. Hence, predictors of the undervaluation are searched in studies on redeployability. According to Penrose (1959), redeployability is enhanced by 'inducements' ― return advantages of new over original businesses, and limited by 'obstacles' ― redeployment costs between them. Inducements were captured as current return advantages of new businesses (Anand and Singh, 1997; Wu, 2013), return volatilities in existing and new businesses (Kogut and Kulatilaka, 1994), or correlation of returns between them (Triantis and Hodder, 1990). While each proxy captures inducements, they perform distinct roles (Sakhartov and Folta, 2013). In particular, return correlation inversely measures inducements as convergence of future returns, reducing the likelihood of future return advantages. Return volatilities directly capture inducements by broadening confidence bands for them and making their possible differences more extensive. The current return advantage directly captures inducements by positioning the confidence band for returns in the new market above the band for returns in the existing market. Obstacles were inversely captured with relatedness

[20] The estimation of the correlation coefficients is based on the data downloaded at http://www.wolframalpha.com.

(Anand and Singh, 1997; Montgomery and Wernerfelt, 1988; Wu, 2013), measuring similarity of resource demands across businesses and reducing redeployment costs.

Beyond the determinants of redeployability, the undervaluation stems from the ambiguity investors have about resources. Empirically, the ambiguity implies variability of beliefs about the resource value and is detected in bid–ask spreads on stock, repurchases of stock by firms, and excess volatility of stock.[21] Theoretically, the ambiguity is due to the limited understanding stock investors have of applicability of resources in new uses (Denrell *et al*., 2003). Such ambiguity may be modeled as uncertainty of costs of redeploying firms' resources to new product markets. In that sense, redeployability is an option with an uncertain exercise price ― redeployment costs. Because an option's undervaluation is enhanced by the degree of ambiguity about the option's determinants (Bernardo and Chowdhry, 2002; Myers and Majluf, 1984), the ambiguity about redeployment costs should be a direct predictor of the resource undervaluation. Treating the investor ambiguity as a model parameter is important because the ambiguity is a determinant whose magnitude is reduced when more instances of redeploying resources out of their current use have occurred. [22] Also, the investor ambiguity is mitigated when stock market analysts converge in the forecasts about returns to operating resources in a particular industry.

Figure 2 summarizes the predictors of the resource undervaluation. The previously established relationships are depicted with solid–line arrows. The relationships between the undervaluation and the determinants of redeployability, explored in the present study, are marked with broken–line arrows. Deriving those relationships will confirm applicability of the strategic

[21] Glosten and Harris (1988) confirmed that bid–ask spreads occur because investors maintain divergent believes about the value of firms' resources. Dittmar (2000) demonstrated that stocks are repurchased when undervalued in the market. Zuckerman (2004) registered excess volatility of stocks of firms operating in industry categories ambiguous to investors.

[22] Investors learn obstacles from past redeployments. However, redeployments are relatively rare and do not cover all possible pairs of existing and new businesses. Learning from rare events is problematic because of confounding idiosyncrasies and exogenous interferences (Starbuck, 2009). Hence, the ambiguity may be reduced, but not completely eliminated.

factor market theory to stock markets and enable to predict the resource undervaluation in those markets. Moreover, comparing the effects of the determinants of redepoloyabilty on the resource undervaluation and on the true resource value will test the redeployability paradox. The next section presents the model solving those tasks and involving the outlined predictors.

Insert Figure 2 here

MODEL

The current section develops a simulation model with tunable determinants of redeployability taken from past research. In addition, the model varies the extent of the ambiguity faced by market investors about applicability of firms' resources in new markets. The model sets those determinants of the resource undervaluation, generates a set of problems with those parameter values, calculates the true value of a firm's resources and their value as estimated by market investors, and adjusts to various levels of the determinants of the undervaluation. By repeating the procedure, the model isolates how the market undervaluation of redeployable resources derives from the determinants of redeployability and the investor ambiguity. An important feature of the model is that it neither imposes nor assumes any relationships between the market undervaluation of resources and the determinants of redeployability. Rather, the relationships are derived by analyzing properties of the function describing the market undervaluation.

The model considers a firm whose current business demands a certain bundle of resources. The true value (V_0^R) of those resources includes a redeployability component resulting from redeployments between the present time ($t = 0$) and the end of resource lifecycle

$(t = T)$.[23] The resource value as estimated by market investors is denoted as V_0^I and estimated separately from V_0^R. Resources initially deployed in one product market (i) can also be used in a new market (j).[24] Each period, resources can be redeployed from i to j, or *vice versa*. Key elements of the model, the firm context and the valuation technique, are elaborated below.

Firm context

The firm context involves inducements and obstacles. To consider inducements, the model specifies returns in i and j as geometric Brownian motions (GBM's). Formally,

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

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

$$dW_{it} dW_{jt} = \rho\, dt, \qquad (3)$$

where C_{it} (C_{jt}) is a return at time *t* when a unit of resources is deployed in i (j); W_{it} and W_{jt} are Brownian motions with the correlation coefficient, ρ; σ_i and σ_j are return volatilities; and μ_i and μ_j are return drifts. Modeling returns as GBM's highlights that they are more uncertain the further one looks into the future. Continuous–time specifications for inducements have precedents (Kogut and Kulatilaka, 1994; Triantis and Hodder, 1990), enabling 'docking' (Burton and Obel, 1998) of the present model to prior models.[25] A critical advantage of the continuous–time specification is that the model captures features of 'fast–paced markets' (Helfat and

[23] Like Kogut and Kulatilaka (1994) and Triantis and Hodder (1990), the model evaluates redeployability for resources having a finite useful life. The assumption may be relaxed by enlarging *T*.
[24] The model generalizes to multiple new markets, but it follows prior research (Triantis and Hodder, 1990; Kogut and Kulatilaka, 1994) and focuses on one new market. Implications of having multiple alternatives markets are discussed later.
[25] Burton and Obel (1998:216) describe that 'docking' is a comparison of designs and results between a new model and an existing model, giving greater confidence in both models.

Eisenhardt, 2004: 1218), where firms encounter frequent and sharp disturbances to returns which would be underplayed by a discrete–time characterization of returns. Another important benefit of the continuous–time model is that, beyond enabling flexibility to redeploy resources, the model highlights managerial discretion to select the optimal time for redeployment. Finally, the selected specification of inducements maps well onto their prior operationalizations depicted in Figure 2. In particular, a difference between C_{j0} and C_{i0} captures the current return advantage; σ_i and σ_j represent return volatilities; and ρ represents return correlation.[26]

Obstacles are modeled based on the insight that redeployment is an adjustment causing the loss in efficiency of deploying resources in the new market relative to their continuous deployment in that market; the loss is mitigated by relatedness (Montgomery and Wernerfelt, 1988).[27] Because the model captures efficiency with market returns, total costs of redeploying resources to j (i) are specified as a product of such returns in the market to which resources are redeployed, C_{jt} (C_{it}); the marginal redeployment cost, S; and amount of resources redeployed (operationalized below). The specification has precedents: Kogut and Kulatilaka (1994: 130) also modeled total switching cost as a percentage of value outcomes, even though their outcome measure was production costs.[28] The model assumes that S does not depend on the direction of redeployment (from i to j *versus* from j to i) and is lower the more related i and j.[29]

[26] There is a technical advantage of using continuous time. In discrete time, step probabilities for returns between periods often get negative for a vast set of return volatilities and correlation (Boyle, Evnine, and Gibbs, 1989). That situation makes the value function undefined over extensive domains, remarkably constraining the generalizability of results of a discrete–time model.
[27] Resource adjustment may be affected by considerations other than efficiency. There may be time lags in redeployment. Despite the apparent relevance of such features of strategic contexts, the model follows Kogut and Kulatilaka (1994) and keeps parsimonious, reducing all obstacles to direct monetary considerations. Introducing additional parameters capturing redeployment lags might compromise the ability to explicate the interaction between inducements and redeployment costs.
[28] There is also an important technical advantage of specifying proportional redeployment costs. Specifying fixed redeployment costs would render the model super–complex. Evaluation of redeployability in a model with fixed redeployment costs would compound possible future scenarios at any time point with past redeployments, blowing the dimensionality of the problem.
[29] The assumption of symmetric redeployment costs is common (*e.g.*, Kogut and Kulatilaka, 1994) and presents such costs as determined by relatedness of a pair of businesses.

The representation of obstacles, as perceived by market investors, relies on the insight of Denrell *et al.* (2003) that market participants face ambiguity about applicability of resources in alternative uses. The idea is operationalized by specifying the investors' view of the marginal redeployment cost, S_t^I, as a random variable such that $E[S_t^I] = S$, implying that investors vary in their beliefs about obstacles, but the mean of their estimates for such obstacles coincides with the true value of the obstacles. Like C_{it} and C_{jt}, S_t^I is assumed to follow a GBM:

$$S_t^I = S_0^I e^{\left[\left(\mu_S - \frac{\sigma_S^2}{2}\right)t + \sigma_S W_{St}\right]}, \qquad (4)$$

where W_{St} is a standard Wiener process uncorrelated with W_{it} and W_{jt}; μ_S is the drift for outsider beliefs about S_t^I assumed to be zero; σ_S is volatility of such beliefs, capturing outsider ambiguity about redeployment costs; and S_0^I is the initial outsider estimate for S_t^I.[30]

Valuation technique

Like any simulation, valuation of redeployable resources is an algorithm imposed on the modeled processes (Davis *et al*., 2007). Logical consistency of the algorithm derives from the mathematical structure of option pricing. The estimation of the true resource value (V_0^R) is done in the complete market specified by Equations 1–3, where market players balance the expected value against the risk of redeployability. Rather than impose restrictions on risk preferences other than non–satiation, the valuation converts returns to a new distribution including a risk premium. The new distribution (described in Appendix) is the equivalent martingale measure Q common in option valuation (Cox and Ross, 1976; Harrison and Kreps, 1979). Using Q does not imply

[30] Because $E[S_t^I] = S$, $S_0^I = S$. Applying the GBM to specify S_t^I enables an efficient approximation of its value with a binomial lattice. With that assumption, the marginal redeployment costs (as perceived by investors) is more uncertain the further investors look into the future.

that market players are risk–neutral. The logic behind *Q* is that the equilibrium between players, gaining and loosing on deals with redeployable resources in a complete market, makes value expected from such deals zero. Also, the valuation based on *Q* should not be confused with predicting actual redeployment choices. The valuation is agnostic about competitive behavior of individual firms, because *Q* abstracts from such behavior to efficiently estimate the true value.[31]

As known in option pricing (Broadie and Detemple, 2004), V_0^R is not analytically tractable because resource redeployment can be exercised at any time (making redeployability an American Type option) and involves costs (making redeployability a path–dependent option). To derive V_0^R, the binomial lattice method of Cox, Ross, and Rubinsten (1979) is used.[32] With the method, GBM's are approximated by binomial processes, whereby returns ($C_{it+\partial t}$ and $C_{jt+\partial t}$) in the next period $(t+\partial t)$ take one of four states: (uu) $C^u_{it+\partial t} = u_i C_{it}, u_i > 1$ and $C^u_{jt+\partial t} = u_j C_{jt}, u_j > 1$ with probability q^{uu}; (ud) $C^u_{it+\partial t} = u_i C_{it}, u_i > 1$ and $C^d_{jt+\partial t} = d_j C_{jt}, d_j < 1$ with probability q^{ud}; (du) $C^d_{it+\partial t} = d_i C_{it}, d_i < 1$ and $C^u_{jt+\partial t} = u_j C_{jt}, u_j > 1$ with probability q^{du}; or (dd) $C^d_{it+\partial t} = d_i C_{it}, d_i < 1$ and $C^d_{jt+\partial t} = d_j C_{jt}, d_j < 1$ with probability q^{dd}. Calculation of q^{uu}, q^{ud}, q^{du}, q^{dd}, u_i, d_i, u_j, and d_j, is described in Appendix. The method also requires discretizing resource capacity, $D_t = \{m_{it}, m_{jt}\}$, allocated between i and j. Parameters m_{it} and m_{jt} are proportions of resources deployed at time t in i and j. Resource capacity, D_t, is discretized so that $m_{it} = \left\{0, \frac{1}{L}, \frac{2}{L}, ..., 1\right\}$ and $m_{jt} = \left\{0, \frac{1}{L}, \frac{2}{L}, ..., 1\right\}$, where L is a whole number.

[31] Triantis and Hodder (1990) also use *Q* to derive value of flexibility to redeploy resources across product markets. Kogut and Kulatilaka (1994: 128) discuss applicability of *Q* to their model of flexibility to redeploy resources across geographic locations.
[32] The binomial lattice method was extended to multivariate options by Boyle *et al*. (1989).

After discretization, the principle of dynamic optimality (Bellman, 1957) can be used to compute the expected true value of resource at time *t*:

$$E^Q[V_t^R] = \max_{D_t}\{F_t\left(C_{it}, C_{jt}, S, D_{t-\partial t}, D_t\right) + e^{-r\partial t}[q^{uu}V_{t+\partial t}^{R,uu}\left(\cdot\right)\Big|D_t^* + q^{ud}V_{t+\partial t}^{R,ud}\left(\cdot\right)\Big|D_t^* + q^{du}V_{t+\partial t}^{R,du}\left(\cdot\right)\Big|D_t^* + q^{dd}V_{t+\partial t}^{R,dd}\left(\cdot\right)\Big|D_t^*]\}. \quad (5)$$

In Equation 5, $F_t\left(\cdot\right) = 1 + (m_{it}C_{it} + m_{jt}C_{jt}) - S\,[\max\left(0, m_{it} - m_{it-\partial t}\right)C_{it} + \max\left(0, m_{jt} - m_{jt-\partial t}\right)C_{jt}]$ represents returns at time *t* corrected by redeployment costs. Terms $V_{t+\partial t}^{R,J}\left(\cdot\right)\Big|D_t^*$ capture future value of resources at time $t + \partial t$ in states $J = \left\{uu, ud, du, dd\right\}$, weighted by probabilities of those scenarios and conditioned on a selected current choice, D_t^*. The risk–free interest rate (*r*) is assumed constant.[33] Expectation $(E^Q\left[\cdot\right])$ is taken with respect to the probability measure, *Q*. To derive present value, V_0^R, calculation starts at the terminal condition $V_T^R = 0$ and proceeds successively backward in time.[34]

The estimation of the resource value by investors (V_0^I) considers that investors face ambiguity about obstacles. As described by Denrell *et al*. (2003), such markets are incomplete, demanding special valuation techniques. The valuation technique for incomplete markets (Riedel, 2009) is used to estimate V_0^I. The method relies on the super–martingale measure $\overline{Q}$, with which valuation in an incomplete market corresponds to the value estimated by ambiguity–averse investors counting on the most pessimistic scenario for an ambiguous parameter. Parameter S_t^I involving ambiguity is discretized with the same binomial approximation (Cox *et*

[33] A more–precise characterization of the firm context would be to model *r* as a random variable. That specification, making the model more complex and remarkably more computationally intensive, is intentionally avoided.

[34] The terminal condition $V_T^R = 0$ means that resources with finite useful lifecycle have zero value after $t = T$. Note that, when $t < T$, values $V_{t+\partial t}^{R,J}\left(\cdot\right)\Big|D_t$ are computed with Equation 5 on the previous step of the algorithm corresponding to $t + \partial t$.

al., 1979) described in the Appendix. After discretization, the Bellman's equation for the resource value as expected by market investors at time t takes the following form:

$$E^{\overline{Q}}[V_t^I] = \max_{D_t}\{F_t(C_{it}, C_{jt}, D_t, D_{t-1}, S_t^{I,u}) + e^{-r\partial t}[q^{uu}V_{t+\partial t}^{I,uu}(C_{it+1}^u, C_{jt+1}^u, S_{t+1}^{I,u})\big|D_t^* + q^{ud}V_{t+\partial t}^{I,ud}(C_{it+1}^u, C_{jt+1}^d, S_{t+1}^{I,u})\big|D_t^* + q^{du}V_{t+\partial t}^{I,du}(C_{it+1}^d, C_{jt+1}^u, S_{t+1}^{I,u})\big|D_t^* + q^{dd}V_{t+\partial t}^{I,dd}(C_{it+1}^d, C_{jt+1}^d, S_{t+1}^{I,u})\big|D_t^*]\}. \quad (6)$$

Equations 5 and 6 differ only in values for the marginal redeployment cost. While the true value (Equation 5) is based on the known value of S, the investor valuation (Equation 6) is based on the most pessimistic (*i.e.*, the highest) estimates, $S_t^{I,u}$ and $S_{t+1}^{I,u}$, for the redeployment cost.

RESULTS

The analysis of the resource undervaluation involves three steps. First, the established result that the investor ambiguity about resources leads to the undervaluation is validated. Second, the known effects of the existing determinants of redeployability on the true resource value are checked. Third, the undervaluation is related to the determinants of redeployability.[35]

Effect of investor ambiguity about redeployment cost on resource undervaluation

The undervaluation of redeployable resources is computed by subtracting investor valuation (V_0^I) of resources from their true value (V_0^R) and scaling the difference by the true value (V_0^R). Figure 3 illustrates how the undervaluation relates to the investor ambiguity about redeployment costs. The undervaluation is present and enhanced by the investor ambiguity, confirming the existing argument (Bernardo and Chowdhry, 2002; Myers and Majluf, 1984). With the used parameter values (hereinafter reported below the respective figure), the undervaluation may be as

[35] 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.

high as 9.6 percent. While there is little surprise in finding that investors facing ambiguity undervalue resources, the result illustrates the need to separate investor valuation from the true resource value and serves as a starting point for exploring whether the undervaluation systematically relates to the determinants of redeployability.

Insert Figure 3 here

Effect of current return advantage on resource undervaluation

Value implications of the first operationalization of inducements, the current return advantage, are illustrated in Figure 4. Panel A reveals an upward–sloping relationship between the true resource value and the current return advantage, reconfirming the existing arguments (Anand and Singh, 1997; Wu, 2013) and validating the model.

Insert Figure 4 here

Panel B of Figure 4 depicts how the undervaluation bears upon the current return advantage. Several features are worth noting. First, divergence of a dash–dot line and a solid line from zero shows that, when the investor ambiguity is present, the undervaluation occurs. When returns in the new market are 10 percent higher than in the original market and investor ambiguity is high (medium), the undervaluation reaches a peak of 9.9 percent (8.5 percent). Second, the left upward–sloping increments of the dash–dot and the solid lines reveal that the true value and the undervaluation are both enhanced by the current return advantage, confirming the redeployability paradox. The result occurs because, when current returns in the new market become too disadvantageous relative to returns in the original market (at the left margin in Panel A), the true value becomes the value attained in the existing business, without redeployability; and there is nothing to undervalue. Third, in the right parts of the lines, the undervaluation declines when the current return advantage rises, disconfirming the redeployability paradox. The disconfirmation emerges because, with very high current return advantages, immediate and non–recurrent redeployment of all resources to the new market becomes optimal and cancels implications of future ambiguity about redeployment costs. Finally, the relative positions of the three lines in Panel B show that the undervaluation is more sensitive to the current return advantage when the investor ambiguity about redeployment costs is higher. The change in the sensitivity suggests that the positive effect of the current return advantage on the undervaluation is positively moderated by the investor ambiguity when the current return advantage is low; the negative effect of the current return advantage on the undervaluation is negatively moderated by the investor ambiguity when the current return advantage is high.

Effects of return volatilities on resource undervaluation

Figure 5 presents value implications of the second operationalization of inducements, return volatilities.[36] Panel A shows an upward–sloping relationship between the true resource value and return volatilities, reconfirming the established relationship (Kogut and Kulatilaka, 1994).

Insert Figure 5 here

Panel B depicts how the undervaluation derives from return volatilities. If the investor ambiguity is present (dash–dot and solid lines), the undervaluation occurs. When return volatility is 0.9 and the investor ambiguity is high (medium), the undervaluation is 15.8 percent (13.0 percent). The upward–sloping lines in Panels A and B reveal that both the true value and the undervaluation are enhanced by return volatilities, confirming the redeployability paradox. The paradox occurs because, when returns become stable (at the left margin in Panel A), future return

[36] To reduce the dimensionality of the visual representation, return volatilities are captured by a single parameter, $\sigma = \sigma_i = \sigma_j$. Estimations, where the markets have different volatilities, do not change the main insights and are available upon request.

differences are unlikely and the true value degrades to the value resources create in the existing business. There is nothing to undervalue in that case. Finally, the relative positions of the lines show that the effect of return volatility on undervaluation is enhanced by the investor ambiguity.

Effect of return correlation on resource undervaluation

Figure 6 depicts value implications of the third operationalization of inducements, return correlation. A downward–sloping relationship between the true resource value and return correlation, revealed in Panel A, corroborates the previously derived relationship (Triantis and Hodder, 1990), validating the part of the model predicting the true value of resources.

Insert Figure 6 here

Panel B presents how the undervaluation relates to return correlation. Divergence of a dash–dot line and a solid line from zero indicates the resource undervaluation. When return correlation is –0.95 and the investor ambiguity is high (medium), the undervaluation is 13.0 percent (10.9 percent). The downward–sloping lines in Panels A and B reveal that, like the true resource value, the undervaluation is reduced by return correlation, confirming the redeployability paradox. When market returns are perfectly correlated (at the left margin in Panel A), future advantages of the new market are unlikely and the true value of resources converges to their value in the existing business, eliminating a base for the undervaluation. Finally, the relative positions of the lines in Panel B show that the negative effect of return correlation on the undervaluation is exacerbated by the investor ambiguity, revealing a negative moderation between the parameters.

Effect of redeployment cost on resource undervaluation

Value implications of redeployment costs are demonstrated in Figure 7. A negative relationship between the true resource value and redeployment costs in Panel A is aligned with the known positive relationship between value and resource relatedness (Anand and Singh, 1997; Montgomery and Wernerfelt, 1988; Wu, 2013), inversely capturing redeployment costs.

Insert Figure 7 here

Panel B of Figure 7 depicts the undervaluation of resources as a function of redeployment costs. As evident from positions and shapes of the lines, the undervaluation is present and highly sensitive to the true value of redeployment costs when investors face ambiguity about those costs. In particular, the downward–sloping parts of the lines in Panels A and B demonstrate that the true value and the undervaluation can be both diminished by redeployment costs. That confirmation of the redeployability paradox takes place because, with high redeployment costs (at the right margin in Panel A), resource redeployability becomes objectively valueless terminating its difference with investor valuation. The disconfirmation of the paradox at the left margin of Panel B emerges because the implications of investor ambiguity about a non–negative value of the redeployment cost deteriorate as expectation for the non–negative cost approaches zero.[37] Finally, the relative positions of the lines in Panel B show that undervaluation is more sensitive to the redeployment cost when investor ambiguity about that cost is higher.

Validation of results

Importance of the results depends on validity of the model. A substantial effort was made to verify that the model is correct and applicable. First, the model used the parameters raised in prior strategy research. Second, the model was kept as close as possible to the referred modeling precedents, subject to ability of prior models to uncover the relations investigated in the present study. Third, the model was 'docked' to prior models by confirming previously established

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[37] 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.

results. Fourth, every new finding in the present section was intuitively explained. Finally, an exhaustive set of tests was run to ascertain whether the reported results are sensitive to changes in the used parameters. While economic significance of the reported results hinges upon the assigned parameter values; the novel theoretical predictions, summarized below, are robust.

Summary of theoretical results

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

H1: The stock market undervaluation of resources is enhanced by the investor ambiguity about the redeployment cost between an original product market and a new product market.

H2: The stock market undervaluation of resources has an inverted U–shape relationship with the current return advantage of a new product market over an original product market.

H3: The stock market undervaluation of resources is enhanced by volatility of returns in either an original market or a new product market.

H4: The stock market undervaluation of resources is reduced by correlation of returns between an original product market and a new product market.

H5: The stock market undervaluation of resources has an inverted U–shape relationship with the redeployment cost between an original product market and a new product market.

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

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

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

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

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

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

Except for H1, the above predictions are uniquely derived by the present study. An approach to empirically verifying those theoretical predictions is sketched immediately below.

TOWARD EMPIRICAL IDENTIFICATION OF RESOURCE UNDERVALUATION

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

$$\begin{aligned} Y_{it} = \beta_0 + \beta_1 X_i + \max_j \{0, \beta_2 \sigma_S + f(S_{ij}) + g(C_{jt} - C_{it}) + \beta_3 \sigma_i + \beta_4 \sigma_j \\ + \beta_5 \rho_{ij} + \beta_6 \sigma_S f(S_{ij}) + \beta_7 \sigma_S g(C_{jt} - C_{it}) + \beta_8 \sigma_S \rho_{ij} \} + \varepsilon. \end{aligned} \quad (7)$$

Variable Y_{it} is 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 behavior in efficient markets. In particular, an acquisition premium paid by a bidder for a target may proxy for resource undervaluation (Laamanen, 2007), under the assumption that the bidder learned the undervaluation of the target's stock in pre–deal due diligence. Similarly, Y_i can be measured as the likelihood that a target accepts a bidder's stock as a means of payment in an acquisition, assuming that the target detected the undervaluation of the bidder's stock in pre–deal due diligence (Faccio and Masulis, 2005). Undervaluation Y_i 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 are the estimated coefficients. Vector X_i denotes variables covering alternative explanations for the resource mispricing in industry i. Parameter σ_S represents the ambiguity faced by market investors about redeployment costs. Intensity of prior resource redeployments out of industry i may inversely capture σ_S, assuming that investors infer redeployment costs from past redeployments. Variance of analyst forecasts for firms in industry i may be another measure for σ_S. Costs S_{ij} of redeploying resources between industries i and j can be measured as an Euclidian distance between occupational profiles in industries i and j. Current returns C_{it} and C_{jt} can be taken from the Compustat Segments 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. Function f and g denote arbitrary functions (*e.g.*, polynomial) fitting the curves in Panel B of Figure 7 and Panel B of Figure 4, respectively. A key feature of Equation 7 is that an alternative industry j^*, corresponding to the strongest undervaluation of redeployability, is rarely known *ex ante*. 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 demands measures of C_{jt}, σ_j, ρ_{ij}, and S_{ij} for all industries. Equation 7 can be estimated via maximum likelihood estimation after making a distributional assumption about the error term ε.

DISCUSSION

The idea that firms, acquiring resources at prices below the true value of those resources, earn abnormal returns is a key insight of the strategic factor market theory (Barney, 1986). Alleged to be true in markets for corporate acquisitions, the insight confronted grave skepticism of scholars believing in stock market efficiency. Even modern, less–restrictive interpretations of the efficient market hypothesis maintain that, while market mispricing is possible, it cannot be exploited to attain abnormal returns. Such mispricing is *promptly eliminated* by the market and *cannot be predicted*. The apparent controversy was not resolved in theoretical work, modeling strategic factor markets as containing a few buyers and sellers experienced in resource deployment and directly trading with each other. The tension was only partially addressed in empirical work, assuming the market undervaluation of firms' resources and estimating *ex post* implications of the assumed undervaluation. The present study makes two steps to resolve the controversy.

First, the field example illustrates the long–delayed market appreciation of resources at Apple Inc., the firm receiving the greatest public attention and scrutiny by parties supporting market efficiency. The example identifies the undervalued resource property — redeployability to the new product market, smartphones. The prolonged undervaluation of redeployability of Apple's resources (while not rigorously tested) is inferred from the insensitivity of the firm's stock price to the boom in the product market to which the firm prepared to redeploy its resources, despite the abundance of signals about feasibility of such redeployment and the firm's intent to exercise it. Additional evidence on the undervaluation comes from analyst valuation of Apple's resources based only on cash flows in the firm's existing businesses. The field example responds to the argument that the resource undervaluation in contemporary financial markets cannot be strategically exploited because the mispricing is promptly detected and eliminated.

Second, the simulation model is developed to derive the systematic relationships between the market undervaluation and the determinants of redeplyability — inducements and obstacles for redeployment. The results of the model illuminate the redeployability paradox — the same factors make redeployable resources both more–valuable and more–undervalued in the stock market. In addition, the model diagnoses how those relationships are moderated by the investor ambiguity about redeployability. The derived theoretical predictions counter the criticism that the resource undervaluation in contemporary financial markets cannot be reliably predicted from the resource properties. Overall, the study justifies the applicability of the strategic factor market theory to acquisitions of resources in markets for companies and provides the operationalization of the resource undervaluation applicable in future empirical work and managerial practice.

Limitations

The simulation model extends the strategic factor market theory. However, the method has some intrinsic limitations. Some critics may argue that simulations are 'too inaccurate to yield valid theoretical insights' (Davis *et al*., 2007: 480). For example, the present study does not ascertain whether the used geometric Brownian processes match real industry dynamics. An alternative approach is to assume that the parameters revert to average values rather than diffuse infinitely. While that alternative may shift the focus from future to current periods, such specification will not destroy the intuitively explained redeployability paradox. Hence, ascertaining the data–

generating processes is merely an empirical issue worth clarifying by testing the predictions with alternative assumptions. The simulation approach also involves an arbitrary assignment of values to model parameters. Extensive sensitivity checks revealed that the results are robust in a wide variety of combinations of the parameters, confirming the generalizability of the results.

Some readers may ask whether the ambiguity resolves if managers signal redeployability to the market and such ability depends on redeployment costs. The idea implies that high values of redeployment costs and the investor ambiguity co–occur. The model, enabling multiple sets of the two parameters, respects that possibility. Empirically, the investor ambiguity can be modeled as endogenous. A caveat may be raised that obstacles are oversimplified and do not capture non–monetary aspects, such as delays involved in redeployment. Such delays are assumed part of the costs. While non–monetary obstacles would substantially complicate the model, future research might explore such additional features. Some readers may be frustrated by restricting obstacles to resource properties. Beyond costs linked to differences in resource requirements, there may be competitive and institutional costs to entering a new market. While such features are important, adding them to the model can make the model intractable and results uninterpretable. Therefore, modeling redeployability in oligopolistic or regulated markets is left for future efforts. Another possible limitation is restricting the undervaluation to redeployability. Alternative sources of misevaluation may include returns in existing resource uses, complimentarity of the acquired resources with other resources kept by firms, and synergy from contemporaneously sharing resources across product markets. The present study pragmatically focuses on what Maritan and Florence (2008) argue to be the main cause of market inefficiency. Finally, some readers may wonder whether firms' managers can ever recognize and attain the true resource value, used as a benchmark for deriving the undervaluation. Like market investors, managers confront ambiguity about applicability of resources in multiple uses, even though the degree of such ambiguity is reduced by the access to the primary sources of data about resources.

Broader implications of market undervaluation of redeployability

The study may be interpreted as arguing that resources are always undervalued in stock markets. The paper does not make that point. There may be many reasons why resources are overvalued. Leaving such features to other research, the study focuses on the undervaluation important for strategizing in strategic factor markets. The focus speaks to the following broader implications.

- The resource undervaluation results in financial constraints bounding efficient resource deployment strategies (Mahoney and Pandian, 1992). The redeployability paradox shows that studies, relating firms' market value to redeployability (Montgomery and Wernerfelt, 1988; Anand and Singh, 1997), are unclear about whether they capture the true resource value or the value as understood and supported by market investors.
- Research on information asymmetries considered intangible resources, which need not be withdrawn to be levered in new uses but 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) 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.
- The operationalization of the market undervaluation motivates future empirical work on arbitrage strategies linked to resource mispricing in the stock market. Examples of the

contexts which can be served by the operationalization are 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).

Conclusion

The present research extends the applicability of the strategic factor market theory to acquisitions of resources in the market for companies. Concluding that the resource undervaluation cannot be predicted and strategically exploited in the stock market due to market efficiency seems premature. The field example illustrates that the resource undervaluation may persist in the stock market for periods longer than is commonly assumed and sufficient to try strategically using the undervaluation. Furthermore, the simulation model specifies the undervaluation as a function of the observable resource properties, enabling the prediction of the undervaluation. The model diagnoses the redeployability paradox — the same factors making resources objectively more–valuable make them more–undervalued in the stock market. The derived relationships between the resource undervaluation and the resource attributes combine to form the operationalization of the stock market undervaluation of redeployable resources. The operationalization appears useful for empiricists testing implications of the strategic factor market theory and for managers seeking for sources of abnormal returns.

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APPENDIX: MARTINGALE AND SUPER–MARTINGALE VALUATION

The market specified with Equations 1–3 is free of arbitrage because there is a non–trivial probability that returns in *i* or *j* will go down in the next period. The market is complete because the number of sources of randomness (W_{it} and W_{jt}) is equal to the number of traded risky assets (C_{it} and C_{jt}). By the first fundamental theorem of finance (Björk, 2004: 137), because the market is free of arbitrage, there exists a martingale probability measure, *Q*. By the second fundamental theorem of finance (Björk, 2004: 146), because the market is complete, the measure *Q* is unique and can be used for deriving the true value of an option traded in the market. Under *Q*, the dynamics for C_{it} and C_{jt} are as follows (Björk, 2004: 183):

$$C_{it} = C_{i0} e^{\left[\left(r - \frac{\sigma_i^2}{2}\right)t + \sigma_i \overline{W_{it}}\right]} \quad \text{(A1)}$$

$$C_{jt} = C_{j0} e^{\left[\left(r - \frac{\sigma_j^2}{2}\right)t + \sigma_j \overline{W_{jt}}\right]} \quad \text{(A2)}$$

$$d\overline{W}_{it}\, d\overline{W}_{jt} = \rho\, dt \quad \text{(A3)}$$

where $\overline{W_{it}}$ and $\overline{W_{jt}}$ are two new correlated Brownian motions with the same correlation coefficient ρ as in Equation 3; *r* is the risk–free interest rate; and all other parameters remain as specified in Equations 1–3.

Because V_0^R is an American type, path dependent option, its value cannot be found analytically (Broadie and Detemple, 2004: 1163). To find V_0^R numerically, the continuous–time processes specified in A1–A3 are efficiently approximated with discrete–time bivariate binomial processes (Boyle *et al*., 1989). Step probabilities on the resulting lattice are as follows:

$$q^{uu} = \frac{1}{4}\left[1 + \sqrt{\partial t}\left(\frac{r - \frac{1}{2}\sigma_i^2}{\sigma_i} + \frac{r - \frac{1}{2}\sigma_j^2}{\sigma_j}\right)\right] \qquad \text{(A4)}$$

$$q^{ud} = \frac{1}{4}\left[1 + \sqrt{\partial t}\left(\frac{r - \frac{1}{2}\sigma_i^2}{\sigma_i} - \frac{r - \frac{1}{2}\sigma_j^2}{\sigma_j}\right)\right] \qquad \text{(A5)}$$

$$q^{du} = \frac{1}{4}\left[1 + \sqrt{\partial t}\left(-\frac{r - \frac{1}{2}\sigma_i^2}{\sigma_i} + \frac{r - \frac{1}{2}\sigma_j^2}{\sigma_j}\right)\right] \qquad \text{(A6)}$$

$$q^{dd} = \frac{1}{4}\left[1 + \sqrt{\partial t}\left(-\frac{r - \frac{1}{2}\sigma_i^2}{\sigma_i} - \frac{r - \frac{1}{2}\sigma_j^2}{\sigma_j}\right)\right], \qquad \text{(A7)}$$

where q^{uu} is probability that $C_{it+\partial t} = u_i C_{it}$ and $C_{jt+\partial t} = u_j C_{jt}$; q^{ud} is probability that $C_{it+\partial t} = u_i C_{it}$ and $C_{jt+\partial t} = d_j C_{jt}$; q^{du} is probability that $C_{it+\partial t} = d_i C_{it}$ and $C_{jt+\partial t} = u_j C_{jt}$; q^{dd} is probability that $C_{it+\partial t} = d_i C_{it}$ and $C_{jt+\partial t} = d_j C_{jt}$; $\partial t = T / N$ is a time step equal to the ratio of the resources' lifecycle, *T*, and the number of steps, *N*. Multipliers u_i and d_i (u_j and d_j) for the states of returns are found as $u_i = e^{\sigma_i \sqrt{\partial t}}$ ($u_j = e^{\sigma_j \sqrt{\partial t}}$) and $d_i = 1/u_i$ ($d_j = 1/u_j$).

The market amended with Equation 4 remains arbitrage–free, but becomes incomplete. In other words, market investors do not know a realization for S_t^I at the current time t and have heterogeneous priors for that realization. The incompleteness implies that the martingale probability measure is not unique, making the risk–free value of an option in the amended market undefined. As suggested by Riedel (2009), the option valuation in the incomplete market is implemented with a super–martingale probability measure $\overline{Q}$, assuming that market prices are dominated by investors believing in the most pessimistic scenario for an ambiguous parameter. To find the most pessimistic (*i.e.*, the highest) value for S_t^I at time t, continuous–time dynamics for that variable are approximated with the same binomial lattice method of Cox *et al*. (1979):

$$p = \frac{e^{\mu_S \partial t} - d_S}{u_S - d_S}, \qquad \text{(A8)}$$

where p is probability that the marginal redeployment cost will go up in the next period, $S_{t+\partial t}^I = u_S S_t^I$. Multipliers u_S and d_S for the ‘up’ and ‘down’ states of the marginal redeployment cost are found as $u_S = e^{\sigma_S \sqrt{\partial t}}$ and $d_S = 1/u_S$.

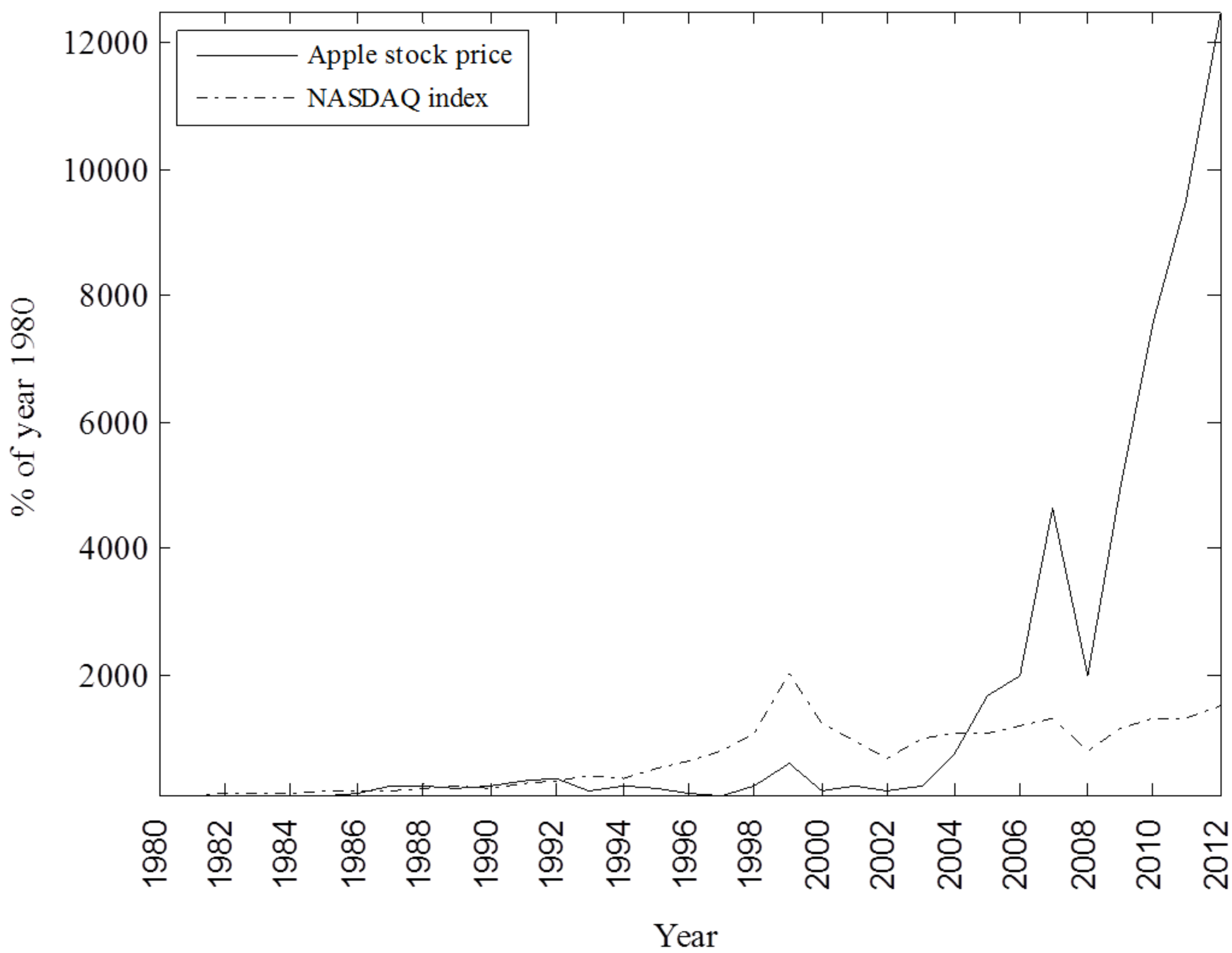


Figure 1. Dynamics of stock price of Apple Inc.

The NASDAQ index and stock prices of Apple Inc. are measured in the last working day of a year and scaled by the respective values in year 1980.

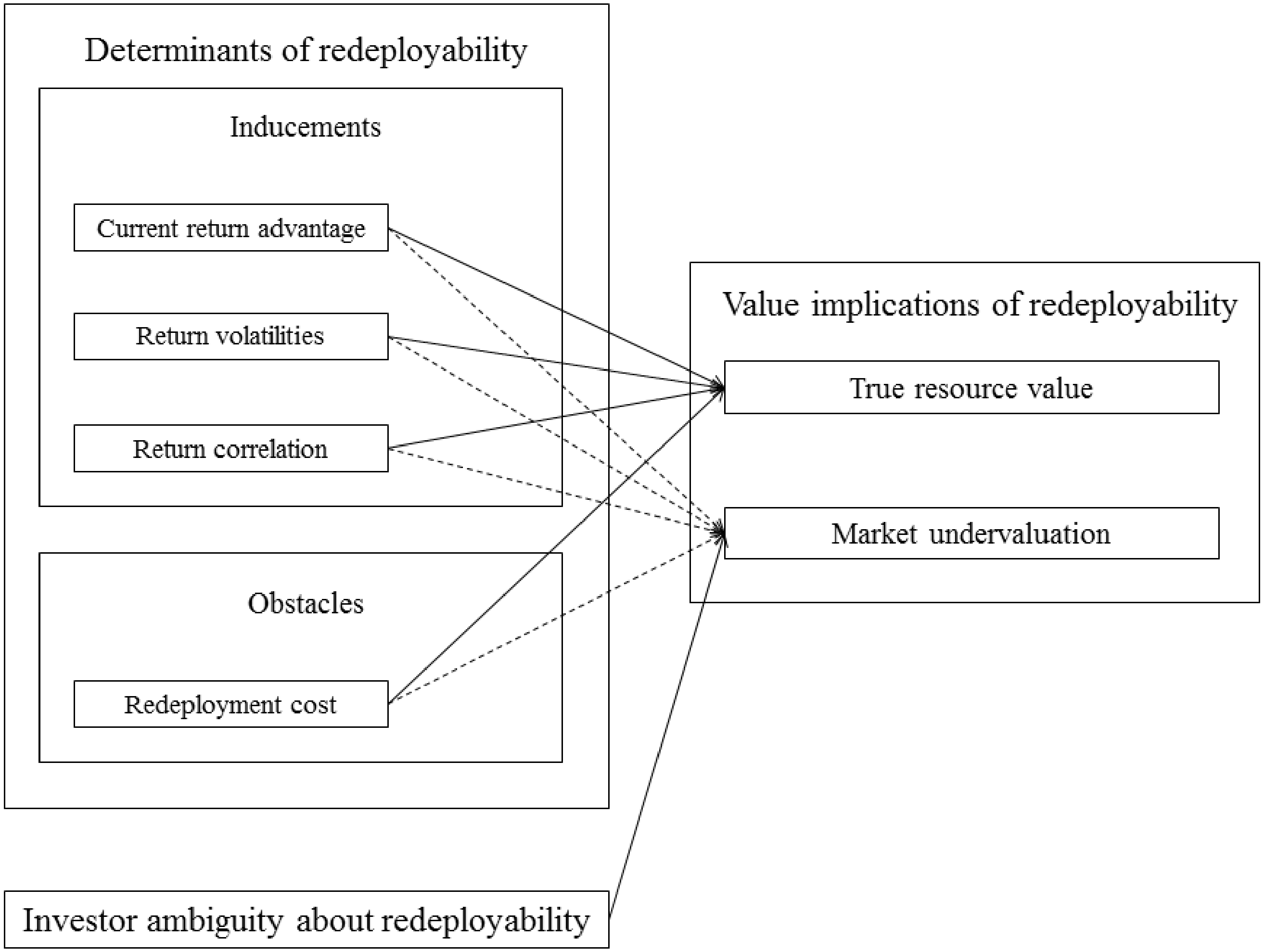


Figure 2. Determinants and value implications of resource redeployability

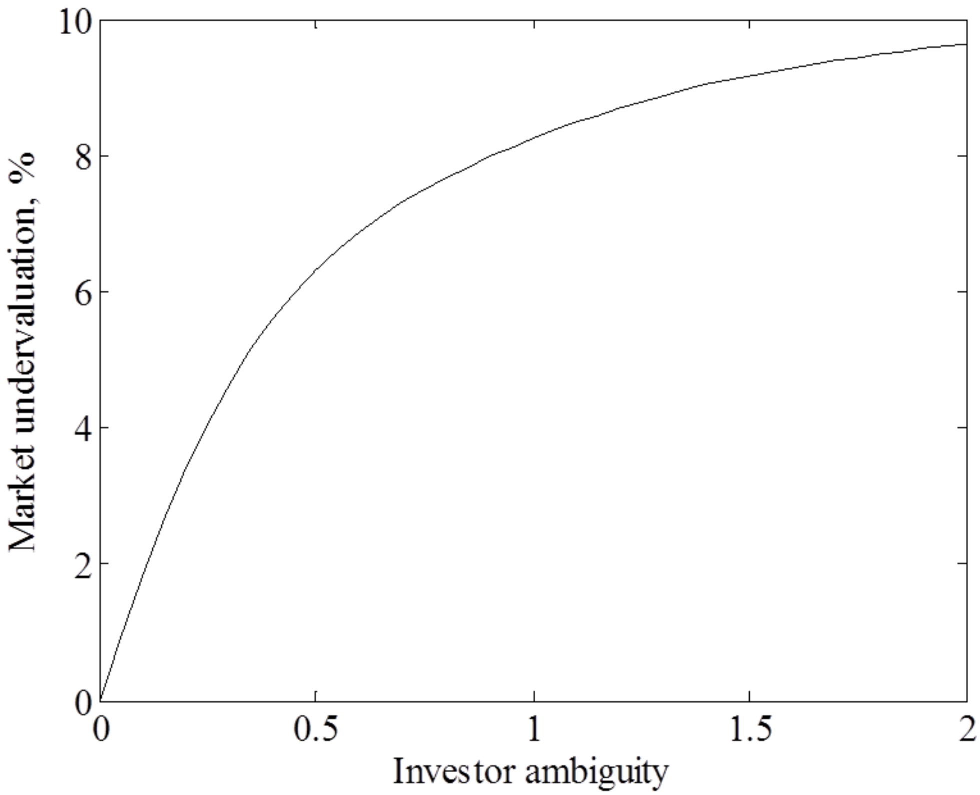
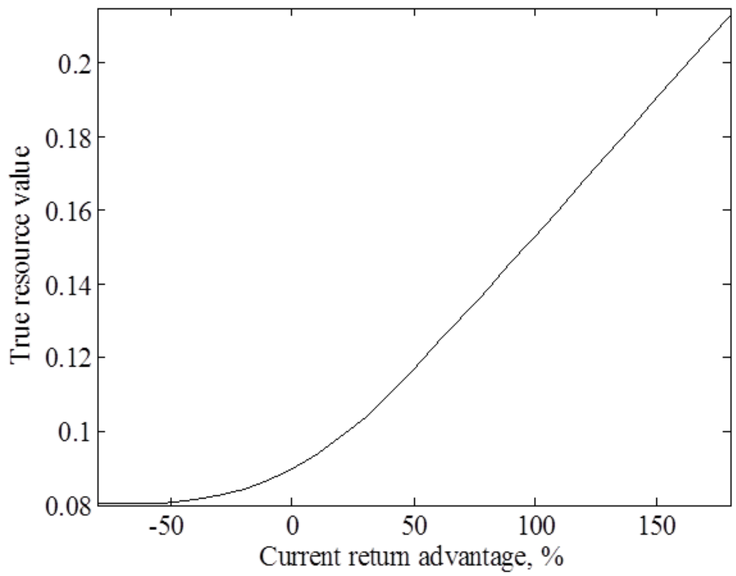
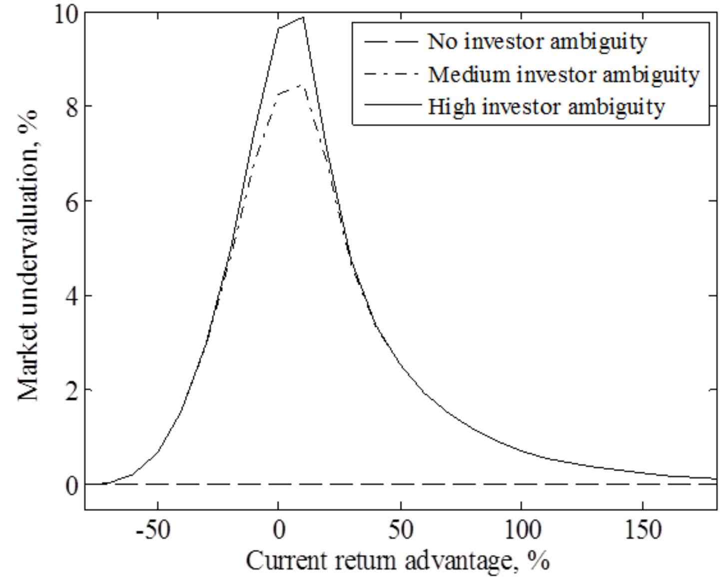


Figure 3. Effect of investor ambiguity on market undervaluation

Market undervaluation of redeployable resources is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 6) 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 4. 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 $L = 1$.



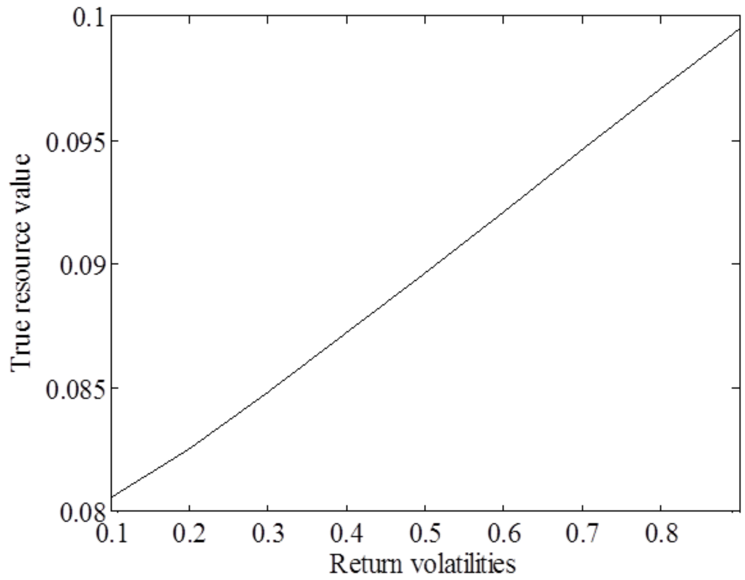
A. Effect of current return advantage on true value



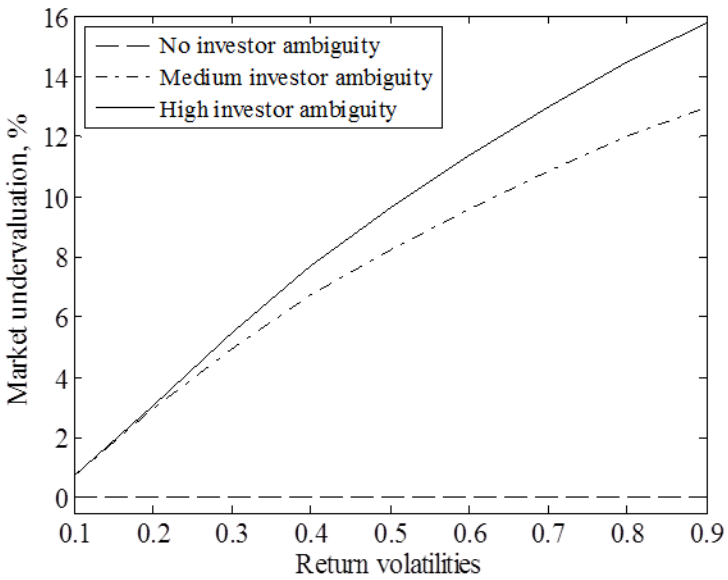
B. Effect of current return advantage on market undervaluation

Figure 4. 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 6) 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 $L = 1$.



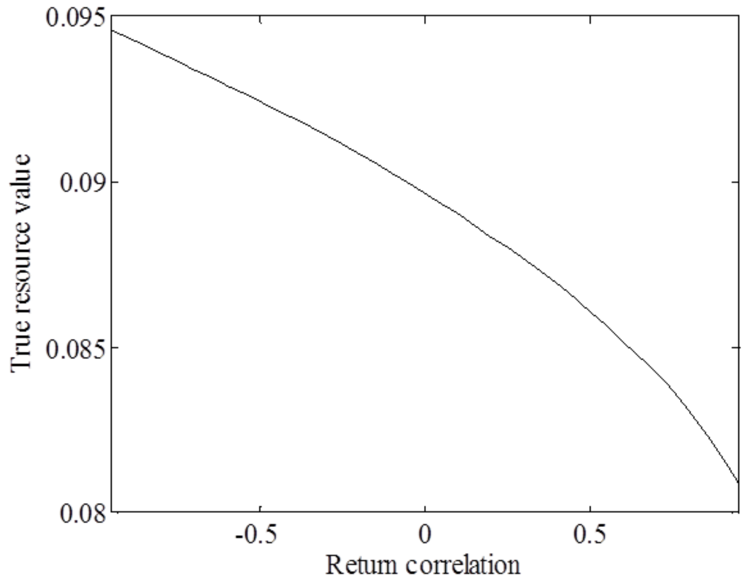
A. Effect of return volatilities on true value



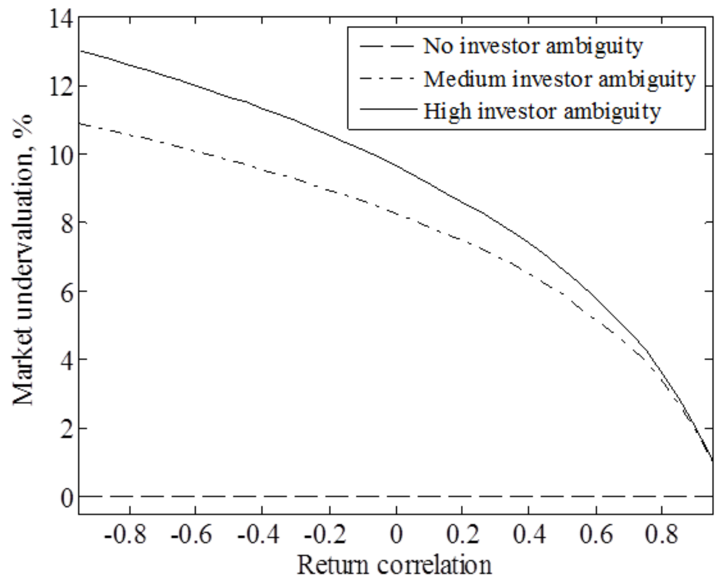
B. Effect of return volatilities on market undervaluation

Figure 5. 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 6) 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 $L = 1$.



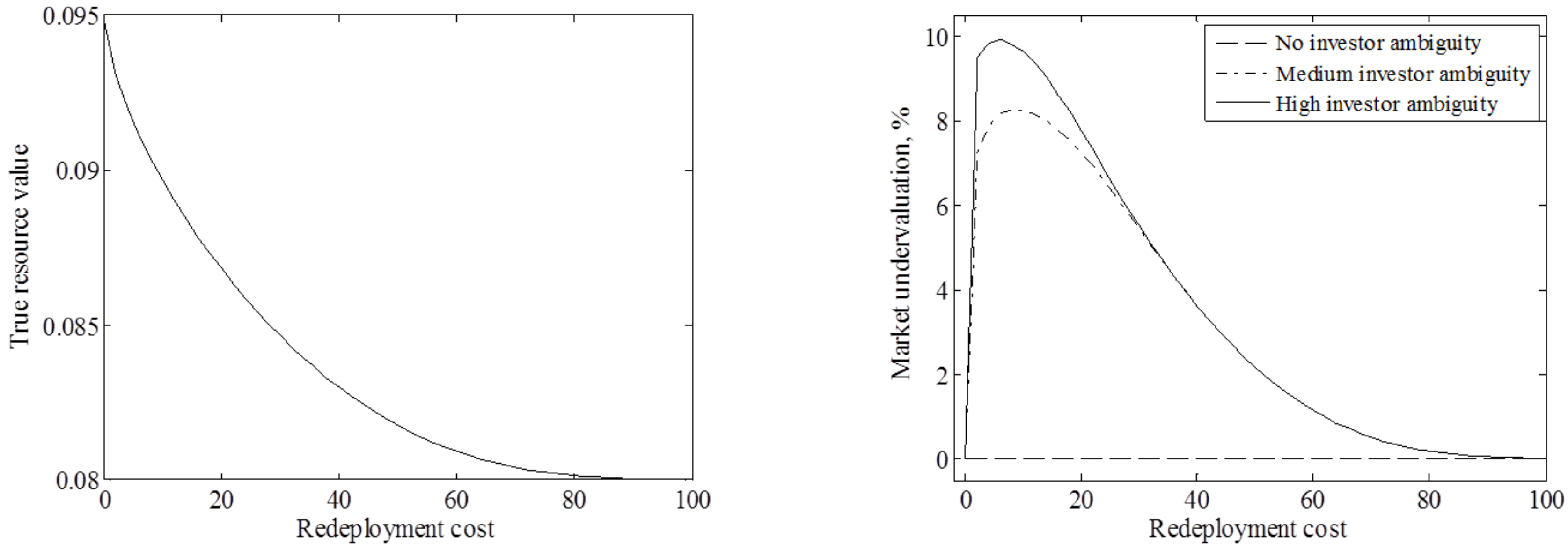
A. Effect of return correlation on true value



B. Effect of return correlation on market undervaluation

Figure 6. 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 6) 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 $L = 1$.



A. Effect of redeployment cost on true value

B. Effect of redeployment cost on market undervaluation

Figure 7. Value implications of redeployment cost

True resource value (V_0^R) is computed with Equation 6. Market undervaluation of resources is computed by subtracting investor valuation (V_0^I) of resources (calculated with Equation 6) 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 $L = 1$.