Market Experiments with Multiple Assets: A Survey

John Duffy Jean Paul Rabanal Olga A. Rud*

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1 Introduction

Experimental finance has made great strides in understanding how market participants price assets in a variety of different settings (see Sunder, 1995; Palan, 2013; Powell and Shestakova, 2016 and Nuzzo and Morone, 2017 for early, as well as more recent surveys). The experimental approach allowed researchers to reduce confounding factors that are present in complex financial markets by controlling environmental factors such as the information available to traders (Bloomfield and Anderson, 2010), or the fundamental value of assets traded, to cleanly isolate the variables of interest. Nevertheless, until recently, most asset pricing experiments have focused on the trade of a *single*, dividend-paying asset following the seminal design of Smith et al. (1988), hereafter SSW. In

*John Duffy (duffy@uci.edu) is at University of California, Irvine, Jean Paul Rabanal (jean-paul.rabanal@uis.no) and Olga Rud (olga.rud@gmail.com) are at the University of Stavanger. We are grateful for the comments received from two anonymous referees and the Editors of the Handbook of Experimental Finance.

actual financial markets, many different types of dividend-bearing assets are traded daily, with the majority of traders holding portfolios of assets rather than individual assets, and participating in multiple markets simultaneously.

In this chapter, we review the small but growing experimental literature on trade in *multiple assets* as well as trade in more complex financial instruments, such as derivatives and indices, the value of which is derived from underlying assets. Experiments that include multiple assets, where at least two or more assets are sufficiently similar, allow us to study whether the no arbitrage condition holds. This condition is an important assumption for formulating predictions under concepts such as interest rate parity, and the law of one price, or for trade with more complex financial instruments such as exchange-traded funds (ETFs). Furthermore, environments with multiple assets expand the range of topics that can be studied, including asset risk premia, price co-movement between assets, and the impact of derivatives and/or indices on the prices of underlying assets.

Our survey is restricted to experiments where the number of assets is two or greater. By assets, we mean *risky* assets where traders face uncertainty about each asset's return, its future price or both. Thus, we exclude asset market experiments where subjects are endowed with a single risky asset and some amount of cash. While cash can be considered an asset, the primary role of cash in most asset market experiments that follow the SSW tradition is to facilitate trade in the single, dividend-bearing risky asset. Further, in most such studies, cash typically earns no rate of return and/or appears via an interest-free loan that has to be repaid to the experimenter, though there do exist some experiments that allow for interest bearing cash holdings.[1] Still, the interest rate earned is typically known and constant so that cash holdings would not be considered risky. We further restrict attention to asset markets where there is actual *trade* among

[1]See Bostian and Holt (2009), Fischbacher et al. (2013), Holt et al. (2017), and Weitzel et al. (2020).

the multiple assets using some kind of market mechanism. Thus, we exclude studies involving hypothetical asset trades or "learning to forecast" experiments, where agents form forecasts of future asset prices and trades are then made optimally for them based on their forecasts.

The papers we review in this survey are summarized in Table 1, which provides the main characteristics of each study, including the number of assets traded and their type (e.g. shares, futures, options), the market trading model and format, e.g. Continuous Double Auction (CDA), Call Market, and treatment variations.[2] Our survey is organized as follows: in section 2 we discuss trade of multiple assets in various SSW environments, with a focus on correlation between assets; section 3 reviews multiple asset experiments conducted under the Capital Asset Pricing Model (CAPM) and other state dependent environments; section 4 examines the impact of trading more complex financial instruments, such as ETFs and derivative assets; section 5 looks at other related work in multiple asset markets. Finally, section 6 concludes with a brief discussion and suggestions for future research.

2 Multiple assets in the SSW environment

We begin with a simple SSW environment where market participants –"traders" – trade multiple, dividend-paying risky assets over a number of periods. In this environment, assets are long-lived and the fundamental value of the assets in each period is determined using simple present-value calculations. Most of the studies presented in this section focus on the impact of correlation between assets on asset prices, and study a variety of topics, including support for the law of one price, the Modigliani-Miller theorem, and incentive schemes.

[2] We omit papers on information aggregation, which appear in the review of Sunder (1995).

Fisher and Kelly (2000) were the first to implement a multiple asset market in the SSW environment with the aim of studying foreign exchange markets. Their market has two distinct assets, *red* and *blue*, whose dividends are either perfectly positively correlated, or independently drawn. They employ an oral, continuous double action (CDA) as the trading mechanism, and conduct 15 sessions, where each session is composed of 15 periods. Dividends are paid out at the end of each six minute trading period, to a separate account. While there were six treatments conducted overall, three of them are of primary interest. In the first treatment, the dividend support for both assets was equiprobable and independently distributed. In the second treatment, while dividends for both assets were perfectly positively correlated, the dividend value for one of the assets was twice that of the other. The third treatment had the same structure as the second, except that the dividends were independently distributed. All subjects started out with the same wealth, though in different bundles, such that some had more cash while others had more assets. Their results show only small deviations in relative pricing in all treatments, which suggests that subjects do trade to eliminate arbitrage opportunities.

Childs and Mestelman (2006) add red and blue currencies to the red and blue assets in Fisher and Kelly (2000)'s experimental design. Therefore, in order to buy the red (blue) asset, traders must have red (blue) currency. The exchange rate between the two currencies is fixed and known to all traders. Overall, there are four treatments which focus on the effects of varying the dividend process (correlation), variance, and/or means of the assets. The authors find strong support for rate of return parity when the two assets have identical dividend processes, or that the no arbitrage condition holds. However, the support for this assumption is weaker when the means and variances of the dividend processes for each asset differ from one another. In other words, as assets become more differentiated, the assumption of complete arbitrage could lead to faulty predictions. Similarly, Chan et al. (2013) extend the work of Fisher and Kelly (2000) to study how differentiating characteristics affect asset prices in an SSW environment. In an environment with two assets, the treatments focus on varying the maturity length and the dividend process, leading to a 2×2 experimental design. The authors find that when assets are differentiated, prices are closer to the fundamental values (bubbles are mitigated).

To study the role of incentive schemes for traders who act as portfolio managers, Kleinlercher et al. (2014) consider a market with two assets with the same final period expected redemption value but different supports: the "low risk" asset has a small variance while the "high risk" asset has a high variance. They find that under a linear incentive scheme, the assets are priced close to the expected redemption value, with a small premium for the high risk asset. However, under a convex bonus scheme that rewards traders according to absolute performance (without any downside penalty), the high risk asset trades at a very large premium relative the low risk asset, which remains correctly priced.

Charness and Neugebauer (2019) use a two asset environment to empirically evaluate the Modigliani-Miller theorem, which states that the debt structure of a firm should not affect it's market value. They use an SSW environment to study the pricing of equity shares issued by two identical firms with two different debt structures (leveraged and unleveraged firms). The trading takes place via a CDA, in two distinct environments where asset returns are either (i) perfectly positively correlated, or (ii) independently drawn. The results suggest a higher level of price discrepancy when asset dividends are independently drawn than under perfect correlation. Charness and Neugebauer (2019) conclude that the market can correct relative mispricing and implement value indifference when asset returns are perfectly correlated. Without that assumption, capital structure may affect the market value of the company contrary to the Modigliani-Miller theorem.

Duffy et al. (2021c) study how traders react to split and reverse split announcements in an SSW environment and using a call market price determination mechanism. In their first treatment, market participants trade two different assets, with perfectly positively correlated returns and increasing fundamental values. At an unannounced time t^*, the asset with the higher fundamental value is subject to a 2-for-1 share split, while the other asset is not. In the second treatment, the fundamental values of both assets (with perfectly positively correlated returns) are decreasing, and the asset with the lower fundamental value is subject to a 1-for-2 reverse split, while the other asset is not. They report that the relative prices of assets do not fully adjust to reflect the changes in fundamental values per share, following both types of splits in the short-run, though in the long-run, relative prices converge to the fundamental values. Furthermore, the authors present evidence that market participants with higher scores on a cognitive reflection test (CRT) price assets closer to their fundamental values, compared to participants with lower CRT scores.

Lei et al. (2001) use the SSW environment with up to two assets whose dividends are independently drawn to study the effect of speculation on asset prices. The main treatment variation in their study is the inability of any subject to buy for the purpose of resale, thus removing the scope of speculative trading. The authors find large departures from fundamental values at high volumes when this restriction is imposed. Ackert et al. (2009) use two classes of assets to study speculation as a cause of price bubbles in an SSW environment. One asset only pays a dividend according to one of the two possible states of nature, while the other asset has a restriction on the upper bound of dividends. In addition to the long-lived assets as in SSW, the authors include a treatment where the asset is short-lived but has the same support as in the long-lived environment. The results show that bubbles are more common when assets are long-lived, and when the dividend payoff is unrestricted.

Ackert et al. (2006) add institutional features to the SSW environment, to study how borrowing and short-selling affect asset prices. In their environment, there is a standard asset and a lottery asset, where the latter pays a large dividend in one of the three possible states of nature, but has the same expected payoff as the baseline asset. The treatment variations switch on/off borrowing and short-selling constraints. They find that when borrowing is allowed and short-selling is prohibited, price bubbles are observed for both assets, and are larger for the lottery asset than the standard asset. When borrowing is restricted, price bubbles are smaller and differences between the standard and lottery asset disappear. However, when short selling is allowed and borrowing is restricted prices converge to fundamental values.

3 Multiple assets in CAPM and Lucas models

Another strand of the literature focuses on testing the predictions of core asset pricing models, including the CAPM, and the dynamic Lucas asset pricing model. The first study to analyze some of the predictions of the CAPM model was Levy (1997). The experimental market had 20 possible assets. Subjects were provided with information on the mean and variance of each asset. In each round, the experimenter elicited the aggregate demand and supply functions to determine the equilibrium asset price to clear the market, thus using a call market format. The study, which focused on the linear relationship between risk and return found strong support for the relationship predicted by the CAPM theory. However, subjects generally held only a few assets and therefore failed to hold the market portfolio. Using an Arrow-Debreu environment, Bossaerts and Plott (2004) also test the predictions of the CAPM. They include two risky assets that were traded in a continuous double auction (CDA) and a loan[3]. Overall, the prices observed in the market are consistent with the highest reward to volatility ratio (or the Sharpe ratio), which supports the predictions of the CAPM model.

In an Arrow-Debreu environment similar to Forsythe et al. (1982) and Friedman et al. (1984), Noussair and Xu (2015) find that when inside information about the nature of correlation (positive or negative) between assets exists, it is quickly incorporated in market prices. However, in the absence of private information, traders may attempt to infer information that is not really there from market activity. In that case, asset prices may deviate from the fundamental value of the assets in the direction consistent with the assumed correlation between assets– when positive (negative) correlation is inferred, asset prices decrease (increase).

Some recent papers have studied the predictions of the dynamic asset pricing model proposed by Lucas (1978), where assets help smooth consumption across time. Asparouhova et al. (2016) include two assets, a tree and a risk-free bond, and cash. The tree yields dividends. The experimental results generally support the theoretical predictions, fundamentals —aggregate consumption— drive changes in asset prices over time. This result is consistent with the imposed concave payoff treatment studied in Crockett et al. (2019), which allows for a single asset trading (trees). Noussair and Popescu (2021) test an extension of Lucas (1978), proposed by Cochrane et al. (2008), where the environment includes two trees whose fundamentals are uncorrelated. They find strong support for the predictions of the two-trees model: (i) there is a contemporaneous correlation between the two assets, indicating co-movement, and (ii) momentum persists in the returns of the shocked asset, though this momentum is also present in the returns of the other non-shocked asset.

All of the studies mentioned so far focus on markets with assets that do not derive

[3]In other experiments, the authors replace the loan with a different asset that pays a secure outcome across all states, e.g. see Bossaerts and Plott, 2002)

value from each other. That is, the assets are independent of one another. In the section that follows, we consider how market participants price assets whose fundamental values are linked to other assets.

4 Indices and derivative assets

Duffy et al. (2021b) introduce exchange traded funds (ETFs) to the SSW environment, using a 2×2 design where one factor refers to the presence/absence of the ETF asset in the market, and the other varies the correlation of asset returns to be either perfectly negative or independently drawn. Thus, the market participants can trade either two or three assets, depending on the treatment. The ETF asset is based on the two other assets in the market, such that each underlying asset has an equal share in the index. Assets are traded in a call market, resulting in a single price per period, for each asset. The results show that when dividends are negatively correlated, ETFs reduce asset mispricing without decreasing market activity (turnover). When dividends are uncorrelated, the ETF has no impact on these same measures. Hence, the authors conclude that when diversification is salient, as is the case for the negatively correlated returns, the existence of the ETF asset can reduce mispricing.

The aforementioned paper was the first to study the ETFs in the laboratory environment, and thus abstained from some important features of financial markets, focusing solely on the role of the ETF in a secondary market (which accounts for about 89 percent of trade according to Investment Company Institute). In a follow-up paper, Duffy et al. (2021a) study whether including an asset in the index creates a price premium using Arrow-Debreu type securities in CDA markets. In this experiment, there are three individual assets {A,B,C} whose payoffs are state-dependent, and a composite asset ETF, which changes composition according to treatment. In the baseline treatment ABC, all three individual assets are included in the ETF, such that $ETF = A + B + C$, and in the $A2C$ treatment, asset B is excluded from the ETF and replaced by an identical asset C, such that $ETF = A + 2C$. Furthermore, the trade of the ETF asset is facilitated by a computerized trader (a bot) who is constrained to keep the ETF in zero net supply, and follow the law of one price.

The authors find strong evidence of an index premium– that is, subjects place additional value on an asset that is included in the index, which is significantly percent higher than that of the identical asset that is excluded. These results are robust to a short-selling treatment, which allows market participants to easily take advantage of mispricings by short-selling the individual state-dependent assets. Moreover, the results from the baseline treatment with state-dependent assets confirm earlier findings of Duffy et al. (2021b) in an SSW environment, which states that the ETF helps reduce mispricing when asset returns are negatively correlated.

Another type of market where asset values are linked to other assets is the derivatives market. In field studies and theoretical work (e.g. see O'Hara, 1997), derivatives have been shown to improve price discovery for underlying assets. We begin our review of experimental derivatives markets with by first examining the effect of futures markets on price discovery in spot markets.

Porter and Smith (1995) were the first to study whether introducing a futures market to the SSW environment can dampen the bubbles observed in that environment. A futures market is introduced by adding an asset which expires at the end of the eighth period, which is about half-way through a market session that lasts for 15 trading periods. The authors find that the presence of a futures market reduces, but does not eliminate, the overpricing commonly observed in the SSW environment. Noussair and Tucker (2006) expand the futures market such that these assets mature every single trading period, to help fix spot market expectations. They conclude that when a complete set of futures is available, mispricing in the spot market can be eliminated. In a follow-up study, Noussair et al. (2016) restrict the number of futures to a single security that matures at the end of the last trading period and find that mispricing persists. Further, the volatility of prices is larger compared to markets without futures. The reasoning behind introducing a futures market to the SSW environment is to study the effect of set expectations– a futures market is meant to create common rational expectations about asset prices, and therefore help market participants backward induct the value of an asset. Thus, having a derivative market can improve price discovery. The results suggests that futures markets can reduce, or in some cases eliminate, the observed price bubbles in the SSW environment.

In an Arrow-Debreu environment, Forsythe et al. (1984) find that adding futures to a two-period asset market speeds up convergence to an equilibrium in the spot market. Friedman et al. (1983) extend the number of periods to three and confirm that future markets accelerate convergence to the perfect foresight price. In another study, Friedman et al. (1984) add information asymmetry by using traders with private information sets, or “insiders”. They find that future markets help stabilize prices under informational asymmetry.

A different type of derivative market is considered by Palan (2010), who study whether digital options can help coordinate trader price expectations and aid in price discovery. The authors find similar overpricing of assets, as in the earlier literature (Porter and Smith, 1995). Jong et al. (2006) study a single digital call option that is traded simultaneously with the underlying asset, where some traders have inside information about the actual value of the asset. The results indicate that the insiders trade aggressively in both the stock and the option, leading to feedback effects between the two markets. Price convergence takes place in both markets simultaneously. When the intrinsic value of the option is positive, informational efficiency is higher in the market for the stock, and volatility is lower.

Kluger and Wyatt (1995) study the informational efficiency of call options on asset prices, using an oral CDA with asynchronous trading of asset certificates and options. They find that options significantly improve the informational efficiency of the underlying asset market. Ackert et al. (2019) include a call option whose payoff depends on the volatility of the underlying asset to study how traders assess volatility, and find that the implied volatility does not equal the actual range. When the volatility is uncertain for the subjects, the implied range is a good proxy of subjects' beliefs.

Weber et al. (2019) consider the pricing of credit default swaps (CDS), which are derivative contracts that pay off only if a company defaults on its debt issue, e.g., a risky bond or mortgage backed securities. In an asset market with risky bonds and CDS, they explore whether *naked* CDS positions, where the CDS owner is *not* required to own the underlying bond (and can buy/sell CDS for purely speculative reasons) should be banned as occurred in the European Union following the financial crisis of 2008 or allowed as in U.S. financial markets. They find that if naked CDS positions are allowed, they are used to hedge bond risks significantly less often than in the regulated regime. Further, the regulation does not affect bond market pricing or trade volume or the concentration of holdings relative to its absence. This is useful evidence on the possible impacts of CDS regulation that would be difficult to assess using field data alone.

5 Other multiple asset markets

In addition to the topics discussed, there are relevant papers that explore the imposition of taxes across different assets, the identification of ambiguity premium in asset prices, and price adjustments.

Using segmented markets to limit the possibility of arbitrage, Füllbrunn et al. (2014) study whether the "ambiguity premium", defined as the price difference between a risky asset and an ambiguous asset, is affected by the market format (call market v. CDA) and asset type (standard risky asset v. ambiguous payoff asset). The authors observe a significant premium when there is a high probability of getting a large payoff in a call market format. Selten and Neugebauer (2019) employ a call market for each of three long-lived assets that pay dividends, and find that excess demand seems to be predictive of price changes, which is consistent with the *Walrasian adaptive price adjustment hypothesis*.

Hanke et al. (2010) study the imposition of a Tobin tax on transaction values in a two asset market environment. The authors find that when there is a unilateral Tobin tax, it causes a shift in transactions and liquidity from the taxed to the untaxed market. When the tax is introduced to both markets, the authors observe that overall trading volume is reduced, while price volatility and market efficiency remains unchanged. Kirchler et al. (2011) study the introduction of a Tobin tax across two alternative market formats, a CDA and a robotized dealer, where the latter provides limit orders (and thus liquidity irrespective of the tax regime applied). The tax is levied to either none, one or both assets available for trading in the market. The authors find that a unilateral Tobin tax increases volatility in a CDA format.

6 Conclusion

Experimental finance has made important contributions to our understanding of asset pricing and market efficiency. This understanding continues to grow as we consider asset markets where *multiple* assets are traded simultaneously. This is not merely a more realistic setting. The consideration of two or more risky assets paying uncertain dividends enables the study of arbitrage across those asset classes and the reasonableness of price differences. By contrast to the single asset pricing environment of SSW where bubbles and mispricing are common, when there are two or more similar, dividend paying assets (e.g., with perfect correlation across assets) subjects seem to have little difficulty in getting the relative prices of the two asset right.

Considering the literature reviewed, we do not yet fully understand why participants fail to price assets according to fundamentals when the correlation across assets is not perfectly positive. However, the literature on derivative assets suggests that the presence of related financial instruments may facilitate convergence to fundamental values. With this result in mind, it would be interesting to assess whether the presence of these and other related financial instruments may be useful for reducing mispricing when assets become more differentiated, and markets more complex.

As for future research, there are a number of interesting questions to explore using multiple risky asset market experiments. For instance, it would be of interest to better understand the pricing of spin-off firms. Historically, such firms and their parent company have outperformed the market for some period of time following the spin-off. Similarly, it would be of interest to further investigate the trade and pricing of dual-listed companies also known as Siamese-twin companies. The dual firm structure arises when two companies have merged and have combined their operations and cash flows, though they continue to maintain separate identities and separate share issues, for example the Anglo- Dutch combinations Royal Dutch/Shell and Unilever. While the prices of the shares of such companies should move together in fixed proportions, in reality they do not and there is still some mystery as to why this is the case. Finally, more work is needed on the role of indexation and the consequences of passive investing behavior (which continues to grow in popularity) for price discovery of the assets that underlie those index assets and market efficiency more generally.

The major challenges in studying multiple asset trades and pricing are 1) the attention required by subjects to operate in such markets and 2) the construction of experimental trading platforms for multiple assets trades that are up to the complex task of mimicking the electronic trading platforms used in actual financial markets. We hope that new innovative designs will be able to overcome these difficulties, possibly by also leveraging the large population of online workers that are now available to make sufficiently thick experimental markets, enabling new insights to relevant financial topics concerning the pricing and trade of multiple assets.

Table 1: Multiple Asset Experiments

This table includes the list of papers reviewed in this chapter. CDA in Trading Format refers to continuous double auction. SSW in Model to the work of Smith et al. (1988) and AD to Arrow-Debreu.

Name	Asset type	Format Model	Treatments or variations
Friedman et al. (1983)	1 share + 1 future	Oral CDA in AD	No futures / futures with three periods / private information / MBA students
Friedman et al. (1984)	1 share + 1 future	Oral CDA in AD	No futures / futures with insiders / MBA students
Forsythe et al. (1984)	1 share + 1 future that expires at terminal period	oral CDA in AD	No futures / futures with two periods
Kluger and Wyatt (1995)	1 share + call option	Oral CDA in AD	Options / large (9) or small (6) market participants / with and without inframarginal traders / graduates and undergraduates
Porter and Smith (1995)	1 share + 1 future that expires at $(T+1)/2$	CDA in SSW	Futures / certain dividends
Levy (1997)	20 stocks	Call Market in Sharpe-Lintner Model	MBA students
Fisher and Kelly (2000)	2 shares	Oral CDA in SSW	Perfectly positive / independent dividends draws
Lei et al. (2001)	2 shares	CDA in SSW	No resale of assets / sale of assets; single / two assets
Bossaerts and Plott (2004)	2-3 shares	CDA in AD	Different asset endowments and loan values
Ackert et al. (2006)	2 shares	CDA in SSW	A high dividend with small probability; vary buy margins and short-selling constraints
Childs and Mestelman (2006)	2 shares	CDA in SSW	Same / different expected dividend/variances
Noussair and Tucker (2006)	1 share + 15 futures, each expires every period	CDA in SSW	The future markets are not open simultaneously
Jong et al. (2006)	1 share + 1 call option	Quote-driven market in Kyle (1985)	Subjects change roles within a session

Ackert et al. (2009)	2 shares	CDA in SSW	Two assets: one asset pays if the state is success, and the other has an upper bound; long-period asset / short-period asset with the same support
Hanke et al. (2010)	2 shares	CDA in Random walk	Tobin taxes to none, one or both assets
Palan (2010)	1 share + digital options	CDA in SSW	One maturity / three maturities
Kirchler et al. (2011)	2 shares	CDA - Dealer market, brownian motion	Market format, and Tobin taxes to none, one or both assets
Chan et al. (2013)	2 shares	CDA in SSW	Different maturity and expected dividends
Füllbrunn et al. (2014)	2 shares	CDA, Call Market in SSW	Market format, and objective probability
Kleinlercher et al. (2014)	2 shares	CDA in SSW	Different variances, and role of incentive contracts
Noussair and Xu (2015)	2 shares	CDA in AD	Positive / negative / no correlation
Noussair et al. (2016)	1 share + 1 future that expires at T	CDA in SSW	No futures / futures
Asparouhova et al. (2016)	1 asset (tree) + 1 bond	CDA in Lucas (1978)	Protocol for perishable consumption: at the end of every nonterminal period, holdings of cash disappear; only cash held at the end of the randomly determined terminal period is credited to participants' final payout accounts
Selten and Neugebauer (2019)	3 shares	Call Market in SSW	Dynamics of adjustment
Ackert et al. (2019)	1 share + 1 call option	CDA in AD	Range of payoff public or uncertain / prob. of states
Charness and Neugebauer (2019)	2 shares	CDA in SSW	Perfectly positive / independent dividends draws
Weber et al. (2019)	one risky bond + CDS	Call Market in SSW	Covered or naked bond positions (with/without CDS)
Duffy et al. (2021a)	3 shares, two of which are identical, + index	CDA in AD	All assets in the index/one of the redundant outside the index and replaced by the other asset in the index

Duffy et al. (2021b)	2 shares + an index	Call market in SSW	Perfectly positive / negative dividends draws, and index /no index
Duffy et al. (2021c)	2 shares	Call Market in SSW	Split / Reserve split under perfectly positive dividends
Noussair and Popescu (2021)	2 assets (trees)	CDA in Cochrane et al. (2008)	The number of units of one asset in circulation is smaller than the other; the former has a greater value due to its diversification potential

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