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WELL DIVERSIFIED EFFICIENT PORTFOLIOS

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Resumen
El método de media varianza es escasamente usado por los inversionistas al momento de decidir sus portafolios de inversión. Una de las principales razones que dan es que los portafolios eficientes se concentran sistemáticamente en unos pocos activos. Este artículo muestra que tal asignación es consecuencia de considerar el retorno y el riesgo del portafolio como magnitudes infinitamente aproximadas. Por el contrario, si la frontera eficiente se considera dentro de cierta tolerancia infinitesimal, como es una centésima de sus valores, no hay uno sino cientos e incluso miles de portafolios eficientes y, de hecho, muchos de ellos están bien diversificados entre activos.

Abstract
Investors scarcely use mean-variance optimization when deciding on their actual portfolios. One of the main reasons they give is that efficient portfolios are systematically concentrated in a few assets. This article shows that such an allocation is achieved when portfolio risk and return are seen as infinitely accurate magnitudes. However, if the frontier is considered within some infinitesimal tolerance, as in a one-hundredth neighborhood, there are thousands of efficient portfolios and, indeed, many of them are well diversified.

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1. INTRODUCTION

Markowitz [1952] mean-variance (MV) optimization is the cornerstone of normative finance, as well as the subsequent basis of much theoretical research. Despite this formal importance, investors scarcely use the method when deciding real portfolios. Practitioners argue that efficient allocations are neither intuitive nor financially valuable. In practice, MV optimization must be implemented with an extensive set of constraints , in opposition to the very idea of providing an analytical solution to the allocation problem[1].

Two causes underlie this non-intuitive behavior. First, MV solutions are extremely sensitive to optimization inputs (see, for instance, Best and Grauer [1991], and Chopra and Ziemba [1993]), which, moreover, are statistical moments, inferred within an error. Thus, the method does not control what Jorion [1992] calls the "estimation error". What's more, these errors are maximized in the optimization process(see Michaud [1989]). Thus, portfolios obtained by MV optimization tend to be unstable and badly behaved[2].

Recent studies (see, for instance, Michaud [1998]) have incorporated risk estimation into the model, propagating the errors to the efficient frontier by means of resampling techniques. As a consequence, the frontier in these models has statistical features, and is no longer a line, but rather, a broad area in the return-risk space.

The second problem of efficient portfolios is their lack of "diversification", in the naive sense of the word. When investors impose the short sales constraint, the MV solution puts all wealth in a few assets. Black and Litterman [1992] pointed to this corner solution problem as the main obstacle for practitioners implementation. Though this problem is related to input-sensitivity, it is not the same. Green and Hollifield [1992] show that extreme positions seem unlikely to be attributable to sampling error.

This article proves the existence of "well diversified" portfolios – in the sense that they distribute wealth among a large number of assets – in an infinitesimal neighborhood of the efficient frontier. We transform "input errors" into "output errors", which means that the return and risk of the final portfolio should not be considered exact mathematical quantities, but rather as measurable variables within some range. We will work under the simplifying assumption that no estimation error is present. All of our results can be extended to account for estimation errors and resampling analysis.

The basis of our work is the profile of risk-return of the whole set of eligible portfolios. The key feature of this behavior is that many of the possible portfolios are crowding towards the efficient frontier (see Corvalan

[2005]). So, there are a huge amount of "almost efficient" portfolios. As an example, consider US gobernment and agency bonds of different maturities, and assume that two portfolios are different if they differ by 1% in any asset weight. If the frontier is considered within a hundredth accurateness there are more that 10^8 efficient portfolios. As Chopra [1991] shows for a 3 asset portfolio, many of them are quite different in composition. We state that there are “well diversified” portfolios close to the efficient but concentrated portfolios.

Our work provides a simple method to compute this well diversified efficient portfolios. Continuing with the bond example, the non-short sales efficient portfolio that provides a risk of $10,0\%$ is diversified among two assets and provides a return of $5,4\%$. If we admit as efficient any portfolio with a hundredth accurateness (10 and 5 base point in risk and return, respectively), we will find allocations that distribute the wealth in the 8 assets, with a 23% of them in positions that were null in the optimal solution. This value increase near 40% if we consider 2 hundredths accurateness and still the whole asset set is positively allocated. The remarkable point is that a hundredth error in the return and risk measures is one order of magnitude lower that the frontier error due to input estimation errors. Besides, such accurateness is within the investor tolerance for the allocation mechanism.

2. THE PORTFOLIOS ARE "CROWDED" IN THE FRONTIER

Practitioners are mostly interested in efficient portfolios. However, there are a huge amount of possible portfolios[3]. In Corvalan [2005] we propose the question about how many portfolios are equivalent in the sense of having "near" values of return and risk. If return and risk are not seen as infinitely exact magnitudes, but rather, as ranges, or "cells", of values, we can count the number of "equivalent portfolios" with risk and return within the cell. Performing this accounting we can realize that close to the efficient frontier the number of equivalent portfolios dramatically increases. In fact, the frontier if a very dense region regarding portfolios, and there are many portfolios equivalent to the efficient ones.

We leave formal definitions for Appendix A, and here introduce some basic notions to show the former statement. For every return-risk pair (R, σ), we define a cell that contains all the pairs in $[R - \Delta R, R + \Delta R]$ and $[\sigma - \Delta\sigma, \sigma + \Delta\sigma]$. We choose ΔR and $\Delta\sigma$ in such a way that the cell is “financially infinitesimal”: negligible for the investor but large enough to include many portfolios with risk and return within it. In order to count the equivalent portfolios in each cell, we need a measure unit to identify between distinguishable portfolios. The scalar unit Δz will be the basis for such a measure. Two portfolios will be different if they differ in Δz in any of their asset weights. During this work we usually use $\Delta z = 0.5\%$ or 1%. Finally we count equivalent portfolios by the function $\rho(R, \sigma)$ which assigns to each cell centered in (R, σ) the number of distinct portfolios with return and risk contained within it.

The following example shows the behavior of the function $\rho(R, \sigma)$. We consider three assets: US equities, US bonds and International Equities[4]. We define the infinitesimal cell by choosing $\Delta R = \Delta\sigma = 5 \times 10^{-4}$ and $\Delta z = 5 \times 10^{-3}$ $(0, 5\%)$. For a risk $\sigma = 12, 00\%$ the higher return is $R^* = 8, 97\%$. Figure (1a) displays $\rho(R, \sigma = 12\%)$, numerically calculated, for R values increasing up to R^*. Similarly, for a return $R = 9, 00\%$ the lower risk is $\sigma^* = 12, 09\%$. Figure (1b) displays $\rho(R = 9\%, \sigma)$ for σ values decreasing up to σ^*.

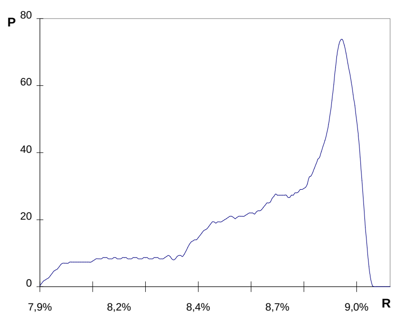

Exhibit 1a. $\rho(R, \sigma = 12\%)$

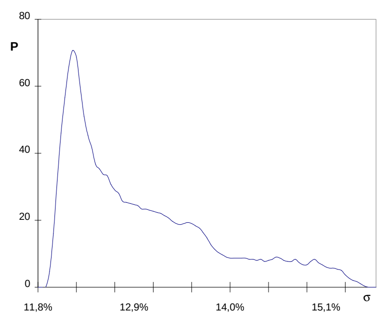

Exhibit 1b. $\rho(R = 9\%, \sigma)$

Both figures indicate that the area near the efficient frontier is the densest region in the whole return-risk space. The uniqueness of the MV solution would seem to imply that the equivalent portfolios would decrease as we approach the optimal set. However, portfolios are crowding near the efficient frontier.

3. A BROADER DEFINITION OF EFFICIENCY

From Exhibit 1 we notice that the number of portfolios is, in order of magnitude, 10^1 and 10^2. However, the equivalent portfolios increase with the number of assets. Consider, as an illustration, that assets are government and agency bonds. Table 1 reports estimated means, standard deviations and correlations for US gobernment and agency bonds of different maturities over de period February 1999 to September 2005. Assume $\Delta z = 1\%$. The number of equivalent portfolios within an arbitrarily neighborhood of the frontier is given by the formula (A.5), where no short sales constraint is imposed. In a 1% neighborhood of the efficient portfolio with risk-return $(10.0\%, 6.8\%)$ there are 1.2×10^8 portfolios. For a millesimal neighborhood the number is about 1.2×10^4.

	US Bonds							
	Government (T)				Agcy.			
	1-3Y	3-5Y	5-7Y	7-10Y	1-3Y	3-5Y	5-7Y	7-10Y
Avg.Ann.								
Mean Return	4.31	5.42	6.07	6.21	4.80	6.41	7.21	8.07
Std.Dev.	6.00	13.16	17.88	22.72	7.06	15.23	20.32	26.68
	Correlations							
UST 1-3Y	1.00							
UST 3-5Y	0.93	1.00						
UST 5-7Y	0.88	0.99	1.00					
UST 7-10Y	0.83	0.97	0.99	1.00				
USAgcy 1-3Y	0.97	0.91	0.87	0.82	1.00			
USAgcy 3-5Y	0.91	0.94	0.93	0.90	0.95	1.00		
USAgcy 5-7Y	0.88	0.96	0.96	0.95	0.90	0.96	1.00	
USAgcy 7-10Y	0.84	0.92	0.93	0.93	0.88	0.94	0.99	1.00
All data are expressed as per cent per annum.								

Table 1: Bond Returns 1992-2002

Our result has several practical implications. The most important one is that to limit the eligible set to the efficient portfolios is a very restrictive condition. If investors consider the frontier within some infinitesimal tolerance, as a hundredth neighborhood, there are not one but some thousands efficient portfolios. This work assumes that a reasonable discretization is to consider return and risk as indistinguishable at a hundredth of their values. The frontier will be equivalent to the narrow area 1 or 2 per cent below it. We remark that this area is negligible when it is compared with the statistical accepted zone given estimation errors. Scherer [2004] indicates that even with 50 years of data the confidence interval of the mean estimate is the same size as the mean estimate itself. Michaud [1998] uses resampling techniques to assign a 10% error to the efficient frontier. Our accurateness for the output measures is about one order of magnitude less.

In the following section we describe how to obtain well diversified efficient portfolios.

4. WELL DIVERSIFIED EFFICIENT PORTFOLIOS

There are many diversification measures. Chamberlain [1983] proposes the sum of squared weights or L_2 norm. Green and Hollifield [1992], interested in the relationship between diversification and the asset number N, declare that the portfolio is diversified if every asset is below a threshold weight of $K(N)$. Bouchard [1997] proposes the L_P norm, which means the sum of the p-power of the weights, and, as limit case, the entropy of weights.

In this article we propose a different criteria. Assuming short sales prohibition, we consider the product of weights as a diversification measure. This function is maximized when all weights are equal to $1/N$, and is minimized (at zero) if any asset has no weight. We recommend such a measure in order to obtain a portfolio with no null asset weight. It was selected simply due to its better performance. Nevertheless, any diversification measure can be used in the method that follows. Table 2 summarizes them all.

$D(w)$	Author
$D = \sum_i w_i^2$	Chamberlain [1983]
$D = \max[w_i]$	Green [1992]
$D = \sum_i w_i^P$	Bouchard [1997]
$D = \sum_i w_i \ln(w_i)$	Bouchard [1997]
$D = \prod_i w_i$	Proposed

Table 2: D(W)

For obtaining well-diversified efficient portfolios, we propose a two step mechanism. The first step performs the traditional MV optimization.In the second step, the investor maximizes any of the functions depicted in Table 2, subject to the condition that the solution be within a neighborhood of the efficient point obtained in step 1. The problem is stated as follows

Step 1. MV Optimization

$$\max_{\{\mathbf{w}\}} \mathbf{w}'\mathbf{r} \qquad s.t.$$

$$\begin{aligned} \sqrt{\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w}} &= \sigma \\ \mathbf{w}'\mathbf{i} &= 0 \\ w_i &\geq 0 \end{aligned}$$

We call $\mathbf{w}^*$ the solution of the MV allocation. Generically $\mathbf{w}^*$ will be badly diversified. We define $(R^*, \sigma^*) = (\mathbf{w}^{*\prime}\mathbf{r}, \sqrt{\mathbf{w}^{*\prime}\boldsymbol{\Sigma}\mathbf{w}^*})$.

Step 2. Diversification Optimization

$$\max_{\{\mathbf{w}\}} \prod_i w_i \qquad s.t.$$

$$\begin{aligned} \sqrt{\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w}} &\leq (\sigma^* + \Delta\sigma) \\ (R^* - \Delta R) &\leq \mathbf{w}'\mathbf{r} \\ \mathbf{w}'\mathbf{i} &= 0 \\ w_i &\geqslant 0 \end{aligned}$$

where investor arbitrarily fixes ΔR and $\Delta\sigma$ depending in his accurateness tolerance.

As an example, we applied the mechanism to the portfolio of bonds considered in Table 1. Table 3 depicts the results, where EF(0.0) is the efficient portfolio, EF(0.5) the well-diversified portfolio in a 0.5% neighborhood of the frontier, EF(1.0) the well-diversified portfolio in a 1.0% neighborhood of the frontier, and so on.

We notice that changes of a hundredths in risk and return provides a portfolio diversified in all assets. Although the two no-null assets in the EF portfolio are strongly overweight, the new portfolios allocate about 15% to 40% of the wealth in other assets (see %D in Table 3).

If we applied the mechanism to the currency portfolio presented in Jorion [1992], for a 12% risk efficient portfolio the allocation is concentrated in 3 of 7 assets. For a hundredth neighborhood, all assets have positive weights, and 20% is located in the 4 efficient-null assets. In both examples, the result is robust along the whole frontier.

	Portfolios				
	EF(0.0)	EF(0.5)	EF(1.0)	EF(1.5)	EF(2.0)
US 1-3Y	0.0	3.0	6.7	11.3	17.0
US 3-5Y	0.0	1.5	3.0	4.5	5.8
US 5-7Y	0.0	1.1	2.2	3.2	4.0
US 7-10Y	0.0	0.6	1.2	1.9	2.5
WG 1-3Y	62.6	64.0	61.2	56.1	49.6
WG 3-5Y	37.4	22.1	16.0	12.8	11.0
WG 5-7Y	0.0	5.8	6.6	6.5	6.2
WG 7-10Y	0.0	1.9	3.1	3.6	3.9
Return	5.40	5.37	5.35	5.32	5.29
Risk	10.00	10.05	10.10	10.15	10.20
%D	0.0	14	23	31	39

All data are expressed as per cent per annum.

Table 3: Portfolios in the Efficient Neighborhood

5. CONCLUSIONS

MV optimization provides, in a remarkable simple way, an efficient portfolio that fulfill some general wanted features. But in practice, we must leave the comfortable idea that exact inputs are introduced in a black box in order to generate exact solutions. In real finance, we can't obtain exact inputs and consequently no method can provide us exact outputs. Both are measurable magnitudes, and quantitative analysis must provide a broad framework, accurate enough to guide the investor to a quantitative solution, but, at the same time, wide enough to apply within some tolerance range.

This article shows that there are well diversified portfolios in an infinitesimal neighborhood of the efficient frontier.

APPENDIX

We consider N assets, and denote $\mathbf{r}$ the mean return N-vector, $\mathbf{\Sigma}$ the return covariance matrix, and $\mathbf{i}$ an N-vector of ones. $\mathbf{r}$ and $\mathbf{\Sigma}$ are obtained by statistical inference of historical data, but we assume that they are exact values. For every return-risk pair (R, σ), we define a cell that contains all the pairs in $[R - \Delta R, R + \Delta R]$ and $[\sigma - \Delta\sigma, \sigma + \Delta\sigma]$. Two portfolios will be different if they differ in Δz in any of their asset weights.

The number of "distinct" portfolios with return and risk within a cell centered in (R, σ) is the Portfolio Density function, and it is noted as $\rho(R, \sigma)$. The following is a formal definition

$$\rho(R,\sigma) = \frac{1}{(\Delta z)^{N-1}} \int_A \delta(\mathbf{z}'\mathbf{I} - 1) dz_1 \dots dz_N \tag{A.1}$$

where A is defined as

$$(\sigma - \Delta\sigma)^2 \leq \mathbf{z}'\mathbf{\Sigma}\mathbf{z} \leq (\sigma + \Delta\sigma)^2 \tag{A.2a}$$

$$(R - \Delta R) \leq \mathbf{z}'\mathbf{r} \leq (R + \Delta R) \tag{A.2b}$$

where the integral (A.1) contains a Dirac Delta δ, indicating that only portfolios satisfying the budget constraint should be taken into account. Hence, the integration area is $N-1$ dimensional, even tough A is N dimensional. Consequently, the unit area of the portfolio, in the denominator, also has $N-1$ dimensions. The condition that the cells be "financially infinitesimal" allows us to conjecture that the function $\rho(R, \sigma)$ is smooth over its domain.

The Portfolio Density can be derived exactly in the efficient frontier if no short sales constraint is imposed (see Corvalán [2005]). The frontier is the set of all the pairs (R, σ) satisfying (see Merton [1972])

$$\sigma^2 = \frac{1}{d}(aR^2 - 2bR + c) \tag{A.3}$$

where $a = \mathbf{i}'\mathbf{\Sigma}^{-1}\mathbf{i}$, $b = \mathbf{i}'\mathbf{\Sigma}^{-1}\mathbf{r}$, $c = \mathbf{r}'\mathbf{\Sigma}^{-1}\mathbf{r}$, and $d = ac - b^2$. For simplicity we assume that ΔR and $\Delta\sigma$ follow the frontier, thus

$$\sigma\Delta\sigma = \frac{(aR - b)}{d}\Delta R \tag{A.4}$$

The Portfolio Density in the efficient frontier is the evaluation of $\rho(R, \sigma)$ given by (A.1) into the points (R, σ) given by (A.3) and $(\Delta R, \Delta\sigma)$ given by (A.4), and it is given by

$$\rho(R,\sigma) = \left(\frac{2^{N+1}\pi^{N/2-1}}{N(N-2)\Gamma(N/2-1)} \right) \frac{1}{|\Sigma|^{1/2}\, d^{1/2}} \frac{(\sigma\Delta\sigma)^{N/2-1}\Delta R}{(\Delta z)^{N-1}} \tag{A.5}$$

Notes

[1] Frost and Savarino [1988] impose financially meaningful constraints on the optimization process, thus obtaining well behavior portfolios.

[2] Jobson and Korkie [1981] simulated data from the same statistical moments previously used to derive an efficient portfolio, and they conclude that this optimal allocation behaves worse that an equal weighted one, when evaluated at the data set.

[3] This can be always done given the huge number of possible portfolios. Assume that two portfolios are distinguishable if they differ by 1% on any asset. For N assets without short sales, the number of portfolios are the combinations of 100 parts (each hundredth of wealth) on N. For 3 assets, the result is 5151 portfolios. For 10 assets, the number is bigger that 10^{12}. For 50, 10^{40}.

[4] Return Means and Standard Deviations are USE=$(10.6, 19)$, USB=$(5.20, 5.5)$, IE=$(8.9, 15.8)$. Correlations are ρ(USB,USE) = 0.192, ρ(USE,IE) = 0.333, ρ(IE,USB) = 0.115. Returns are adjusted in order to have the market weights $(38, 2\%, 27, 5\%, 34, 4\%)$ as the mean variance solution. The data is obtain from Idzorek 2003, Zephyr Advisor.

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