

Fritz, Oliver

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Optimal Management of a Regional Income and Pollution Portfolio

Oliver M. Fritz¹

Abstract

Regional policy makers can react to structural changes and their economic consequences, but may also have the option to actively promote such changes in order to accomplish their policy goals. In the present analysis, the regional portfolio framework originally proposed by Conroy (1974) is applied to find the optimal regional industrial structure given the conflicting goals of industrial growth, risk minimization, and emissions prevention. Interindustry linkages are incorporated to the portfolio maximization problem by adding an income multiplier table derived from a quantity-adjusted dynamic general equilibrium model for the Chicago region. The results reveal that the inclusion of both interindustry linkages and emissions constraints notably reduces the potential for efficiency gains through industrial diversification. Furthermore, risk reduction through a more equal sectoral distribution is in conflict with pollution prevention efforts that aim at minimizing the shares of polluting sectors.

¹Institute of of Technology and Regional Policy, Joanneum Research, Vienna, Austria. The author wishes to thank Geoffrey J.D. Hewings of the Regional Economics Applications Laboratory and an anonymous referee for helpful comments. I am also grateful to my wife Maria T. Valderrama for editing and critically reviewing my work.

1 INTRODUCTION

also with unnecessary fluctuations in business activities, since they cause inefficiency. The diversification of a region's industrial base is pursued to make a region more independent of national business cycles. The optimal industrial mix has been discussed in the literature for quite a while and several measures have been suggested.² This paper uses regional portfolio theory, a measure of industrial diversification proposed by Conroy (1974), to show the possible tradeoffs that occur when regional policy deals with income growth, a more stable economy and negative externalities from production activities. A model that takes into account interindustry linkages and industrial air emissions is applied to the Chicago metropolitan region.

In the following section the theoretical and empirical underpinning of this model are presented. Section 3 describes the model. Section 4 discusses the results and finally section 5 contains policy implications and recommendations for further research.

2 REGIONAL PORTFOLIO THEORY

In his seminal work in the early and mid seventies, Conroy (1972, 1974, 1975) makes use of financial portfolio theory³ to analyze regional industrial diversification. It is assumed that the residents of a region act like investors, who draw from the various resources available in the region (natural and human resources and capital) and want to utilize them efficiently in order to maximize their welfare. The resources are transformed into returns (e.g., income, employment or output) by economic activities, which are commonly divided into industrial categories. These industries are the assets in the regional portfolio. Like financial returns, the returns of regional industries are stochastic. Unless residents are risk neutral their goal will be to maximize returns, given that a certain level of risk is not exceeded, or minimize risk, given that a certain level of returns is attained.⁴

Different portfolios contain different combinations of industries and can be characterized by their mean and variance. Regional policy makers, who are assumed

² For a discussion of the history of the economic diversity and instability literature see Kort (1981).

A critical discussion of various diversification measures is also included in Conroy (1974).

³ Financial portfolio theory was developed by Markowitz and Sharpe in the 1950's and 1960's (see e.g., Markowitz, 1952, and Sharpe, 1970).

to know the region's welfare function, want to maximize regional income or employment, but try to avoid the risk of destabilizing fluctuations in income or employment levels, caused by regional, national or international business cycles. Their goal is to efficiently diversify the regional portfolio, i.e., choose the optimal industrial mix. Choosing the optimal portfolio by maximizing a mean - variance model will yield a good approximation of the welfare maximizing solution, even if the distribution of asset returns is not exactly normal (see Sharpe, 1970, and Levy and Markowitz, 1979).

~~which coincides with the welfare maximizing solution if the welfare function is quadratic and returns are normally distributed (see e.g., Sharpe, 1970, and Levy and Markowitz, 1979).~~

The policy makers' decision problem can be described by the following optimization problem:

$$\text{maximize}_{w_i} \sum_i w_i r_i - \frac{\lambda}{2} s_p \quad (1)$$

where r_i is the expected rate of return of industry i , w_i is the relative weight of industry i in the portfolio; λ is a parameter characterizing degree of risk aversion with $\lambda=0$ for risk neutral preferences, and s_p is the portfolio variance, which is a weighted sum of individual industries variances and their covariances.

$$s_p = \sum_i \sum_j w_i w_j s_{ij} = \sum_i w_i^2 s_i^2 + \sum_i \sum_{j \neq i} w_i w_j s_{ij} \quad (2)$$

From equation (2), ~~it is immediately obvious that a regional diversification strategy aimed at attracting stable industries, i.e., industries with low variances, will lead to the risk minimizing portfolio only if all the industries are stochastically independent. Such an assumption seems highly unrealistic, given that a~~ it is obvious that if an industry's returns do not have zero covariance with other industries' returns, then it is not only its own variance that is important for its contribution to the region's variance, but also its covariances with other industries. As a matter of fact, in any regional socio-economic system the various activities and actors are linked in many ~~different ways. But even if a regional economy without any intraregional linkages existed~~ ways, leading to positive and occasionally negative covariances. For example, most industries' wage income is negatively correlated with total transfer payments received by regional residents. Even

⁴ This approach follows that of a rational investor, who maximizes returns and minimizes risk, and goes back to Markowitz (1952).

if technological and policy linkages did not exist, stochastic dependence would result from the industries' dependence on the national economy.

~~business cycles and will be procyclical for some, countercyclical for others. This co-movement of regional industries and national economic indicators implies interdependence.~~

The universe of portfolios can be projected into a return-variance space. The efficiency frontier is defined as the locus of all portfolios whose expected return cannot be increased without increasing its variance or whose variance cannot be reduced without lowering its expected return. The points on this frontier are the solutions to the quadratic programming problem of equation (1). The optimal portfolio maximizes regional welfare and is located where the welfare indifference curve is tangent to the efficiency frontier.

The first attempt to explicitly model the return-risk tradeoff in a regional context was undertaken by St. Louis (1980). Other examples can be found in Brewer (1984), [Bolton \(1986\)](#), Board and Sutcliffe (1991), Gilchrist and St. Louis (1991), Lande (1994) and Hunt and Sheesley (1994).⁵

Recent work has addressed several conceptual and empirical problems that arise from the application of the portfolio framework to the analysis of regional industrial diversification and has sought to improve the theoretical and methodological basis of regional portfolio theory.

In particular, empirical applications of regional portfolio theory show that results differ significantly depending on which measure of return and risk are used. Board and Sutcliff (1991) and Bolton (1985, 1985~~6~~) use regional income to approximate returns. The latter includes unearned income components like capital income from private capital goods located in the region and owned by its residents, property income from outside the region, imputed value of public goods, regional government taxes and imputed value of benefits from environmental goods and services. Most empirical applications, however, use sectoral employment, instead of income, as returns (e.g., St. Louis 1980, Lande 1994, Hunt and Sheesley, 1994). ~~Board and Sutcliffe, 1991, for the use of income as returns~~. This is mostly due to data problems but is acceptable if employment is the focus of a region's industrial diversification policy.

⁵ E.g. Bolton (1986, 1989), Sherwood-Call (1990), McKillop (1990), Schoening and Sweeney (1992), Siegel et. al. (1994), Hunt and Sheesley (1994). For a more comprehensive review of the relevant literature and conceptual and empirical issues see Fritz (1996a).

One commonly applied approach to compute returns is to calculate the growth rates of sectoral employment (or income) levels and adopt the mean as a measure of expected return:

$$\hat{r}_i = \frac{1}{T} \sum_t \frac{E_{it+1} - E_{it}}{E_{it}} \quad (3)$$

where \hat{r}_i is the expected employment growth rate, E_{it} is the i 'th industry's employment level at time t and T is the total number of time periods in the planning horizon (see, e.g., St. Louis, 1980). Every movement of the growth rate to a level above or below the mean is regarded as an unexpected variation in returns. The elements of the covariance matrix of sectoral employment growth can be described as:

$$\hat{s}_i^2 = \frac{1}{T-1} \sum_t (g_{it} - \hat{r}_i)^2 \quad (4)$$

$$\hat{s}_{ij} = \frac{1}{T-2} \sum_t (g_{it} - \hat{r}_i)(g_{jt} - \hat{r}_j) \quad (5)$$

where g_{it} are the sectoral employment growth rates at time t . The portfolio return is computed as the sum of sectoral growth rates, multiplied by the sectoral shares in total employment. Another approach widely used defines detrended employment levels, instead of growth rates, as expected rates of return and calculates the covariance matrix accordingly (see, e.g., Conroy, 1975).

Since it is unclear how residents or the regional planner form their expectations, any method to compute expected returns and their probability distribution remains somewhat arbitrary. More sophisticated measures of unexpected variations (and thus risk), based e.g. on trend cycles (Bolton, 1986) have been applied in the literature, but there is no generally accepted rule to distinguish anticipated from unanticipated variations. As Kurre and Woodruff (1995) have argued, an economy fluctuating less from its long-run trend is more efficient, no matter if these fluctuations are anticipated or not, which puts the measurement issue into perspective.

The growth rate approach suffers from the fact that the weights used in an objective function like (1) - commonly the sectoral income or employment shares - are correlated with the returns. Therefore, if the actual industrial portfolios over the sample period are compared, the economy will be shown to move gradually towards a portfolio with higher total return. Using income or employment levels, on the other hand, is not consistent with financial portfolio theory, where rate of returns are applied.

Furthermore, there is no obvious reason to conclude that an industry with low income or employment levels generates less return than an industry with high levels of income or employment. If levels are employed, the expansion of individual industries or total return has to be restricted by upper (and possibly lower) bounds, which should reflect regional policy's ability to induce sectoral income or employment changes. Setting these bounds may generate an artificial return-risk tradeoff, when, as in Board and Sutcliffe (1991), industries with high variances are assumed to have higher returns (higher potential for change).

Another issue that is relevant for the empirical analysis carried out in the next section has been pointed out by Sherwood-Call (1990): Contrary to financial portfolio theory, several characteristics of regional economies prevent the a priori existence of a risk-return tradeoff. While a financial investor wants to be compensated for securities that show higher volatility and will therefore buy those securities only at a lower price (which implies a higher return), a regional policy maker may not have this liberty. First, a given industry might perform differently depending on its location; second, comparative advantage limits a region's ability to diversify; and; third, industries are not goods which can be freely traded among regions (Sherwood-Call, 1990, p. 19). Hence there is no clear justification for or against, the existence of a risk-return tradeoff and thus a concave efficiency frontier for regional portfolios. Most empirical examples of efficiency frontiers in the literature, however, show the 'right', concave, shape (e.g., St. Louis 1980, Brewer 1984, Hunt and Sheesley 1994, Lande 1994), ~~suggesting that cyclical industries exhibit higher growth rates than more stable industries.~~

Finally, a major difference between financial and regional portfolio theory concerns the fact that unlike financial assets, shares of regional industries cannot be changed independently, due to interindustry linkages and other general equilibrium effects, representing the region's economic structure. These structural links restrict the solutions to regional portfolio models, since altering the shares of individual industries will indirectly effect other industries' shares in the portfolio. Different authors have offered solutions to this problem ranging from input-output modelling approaches (Cho and Schuermann, 1980, Siegel, 1994), regional general equilibrium modelling (Gilchrist and St. Louis 1991, 1994a, 1994b) or adding multipliers of regional export industries (Hunt and Sheesley, 1994).⁶

⁶ For a more detailed review of this line of work see Fritz (1996a).

In the next section, a regional portfolio model is introduced that addresses the problems mentioned above. In particular, it attempts to incorporate structural linkages and offers an extended specification of regional returns. Efficiency frontiers are estimated to illustrate the empirical results.

3 REGIONAL INCOME AND POLLUTION MODELS WITH INTERINDUSTRY LINKAGES

The model used here describes an alternative method to include interindustry linkages in the regional portfolio framework. Furthermore, negative pollution externalities, which have been excluded from existing models, are integrated in the portfolio framework by reducing the returns of industries generating such externalities.

The main contributions of the paper are:

- *Total personal income growth data, classified by industrial sectors, are employed in the estimations instead of using employment as indicator of industrial returns.*
- *The model accounts for interindustry linkages by including a sectoral income multiplier table derived from a regional econometric input-output model.*
- *The portfolio model is restrained such that sectoral income levels can only be increased or decreased within certain bounds; induced income growth is restricted as well.*
- *Industrial air emissions are included as a function of sectoral income levels to account for environmental externalities.*

Efficiency frontiers are estimated using an interindustry portfolio model. Sectoral income growth rates serve as a measure of returns, where income is defined as wages and salaries generated by each sector. As Bolton (1986) has pointed out, income should include not only labor earnings but also other types of income. However, the regional econometric model employed in the empirical part of the paper offers little information to incorporate these income components. By discounting sectoral income by emission generation, the analysis nevertheless includes a nonpecuniary income component. The variance-covariance matrix is estimated according to equations (4) and (5).

A regional econometric input-output model (CREIM) developed for the Chicago region (see e.g., Israilevich, Hewings et. al. 1994, Schindler et. al. 1994) is used to derive an income multiplier table. The elements in this table, one for each combination of industries, are partial derivatives and represent changes in industry i 's income level, induced by an expansion or contraction in industry j 's income. They are derived by increasing one sector's income level (resulting from an increase in final demand) and observing the new sectoral income vector after the model has converged to a new equilibrium.⁷

Using this multiplier table, the socio-economic structure of the Chicago metropolitan area becomes a constraint in the optimization problem. Any change in a sector's weight is equivalent to a (positive or negative) income shock which disturbs the model's equilibrium. Changes in other industries follow, first due to intermediate demand changes, then as the result of induced income effects. Finally, the model reaches a new equilibrium, with all sectoral income levels changed as well as the sectoral weights used in the portfolio model. One sector's weight can therefore not be changed independently of other sectoral weights.

Contrary to a similar approach applied by Hunt and Sheesley (1994), industries are not separated in exogenous export and endogenous non-export oriented activities, although in the empirical application of the model it is assumed that policy makers cannot directly change the income levels for some industries (e.g. agriculture, services etc.). Additionally, multipliers are estimated for all industries in the regional economy.

to minimize portfolio variance. Regional export sector industry multipliers serve as additional weights for the variance-covariance matrix in this objective function and thus represent the interdependent industrial structure in the regional economy.

Total air emissions are estimated for different portfolios on the frontiers, assuming that emissions are proportional to sectoral income levels. It has been shown for Chicago (see Fritz 1996b) that despite the fact that only a few industries are directly responsible for most of the industrial emissions released, the indirect pollution generation through the demand for intermediate goods is significant and therefore should not be ignored. A model which does not take into account the interdependence

⁷ These multipliers are type I income multipliers as defined, e.g., in Miller and Blair (1985), p. 107, as the direct and indirect income effects of a new dollar's worth of final demand for a sector divided by the initial labor income effect, i.e. the additional income payment to workers resulting from the initial final demand change.

of industrial production will consequently underestimate total pollution generation and its negative welfare effects.

Pollution constraints will be introduced into the model in two ways: First, an upper bound on total emissions will be specified to reflect discharge limits which may be imposed by environmental regulators to maintain regional air quality standards. Second, expected returns will be discounted by the value of pollution damages, which are computed based on shadow price estimates for certain pollutants. The measure of portfolio return net of environmental damages is computed as follows.

The ratio of net income (income discounted for pollution externalities) to undiscounted income is:

$$\frac{Y_i - \mu_i P_i}{Y_i} = \frac{Y_i - \mu_i c_i Y_i}{Y_i} = 1 - \mu_i c_i \quad (6)$$

since pollution is proportional to income: $P_i = c_i Y_i$, where Y_i is the income level of industry i , P_i denotes the level emissions of industry i , ~~μ_i is the shadow price of these emissions and~~ c_i is industry i 's pollution coefficient (emissions of industry i per unit of industry i 's income). μ_i is the shadow price of emissions and reflects the average social cost induced by one unit of P_i . Ideally, μ_i is a function of total emissions in the regional economy (and therefore depends on Y_i and the income levels of all other sectors in the regional economy) and represents a nonlinear relationship between social damages and emissions. However, since the estimation of such a nonlinear damage function is beyond the scope of this paper, a linear relationship between emissions and social damages is assumed.

The portfolio returns can then be written as:

$$\begin{aligned} & \sum_i w_i R_i (1 - \mu_i c_i) \text{ for } R_i > 0 \\ & \sum_i w_i R_i (1 + \mu_i c_i) \text{ for } R_i < 0 \end{aligned} \quad (7)$$

where R_i is the income growth rate and w_i are the sectoral weights.

Four different types of portfolio models are estimated all of which specify a constrained quadratic programming problem. The mathematical description of the models is included in the Appendix. Models 1 to 3 are comparative static models, while Model 4 is dynamic; they apply different ways of dealing with pollution externalities: Model 2 includes an upper bound on emissions, while in Model 3 a shadow price is put

on these emissions. Model 4 sets a pollution constraint at the end of the planning horizon and thus represents the case of a region which is given a certain number of years to reach, for instance, air pollution attainment levels

4 AN EMPIRICAL APPLICATION

The interindustry portfolio model is estimated for the Chicago metropolitan area, using an annual income time series for thirty-four industries from 1969 to 1992. Sectoral income is measured as the total amount of wages and salaries within an industry (and thus does not include non wage and salary income). For the manufacturing sector, data at a two digit SIC level are available; other classifications contain several two digit industries. Since the objective of a regional portfolio analysis is to recognize future potential for diversification, predicted average growth rates from 1993 to 2010 are used as a measure of future returns. More than half (19 out of 34) of Chicago's industrial industries have negative predicted income growth rates for that period, suggesting that total average growth can be increased by reducing the weights of these sectors.

The computational procedure for the elements of the variance-covariance matrix employs past income growth rates and follows equations (3) to (5). Using CREIM, a derived sectoral income multiplier table is extracted to predict the impacts of future income shocks. All elements on the diagonal of this table are greater than one, while, with a few exceptions, all off-diagonal elements are below one. In order to compare the future industrial portfolio, as predicted for Chicago, with the optimal portfolios resulting from the solution of the optimization problem, the predicted sectoral income levels of the year 2010 are used as base income levels.

While all the weights have lower limits of zero, the income policy variable d , representing sectoral income changes induced by regional planners, can either be negative or positive. It is bounded, however, based on the consideration that, unlike equities in financial portfolios, industries cannot be traded freely among regions, but have to be given incentives by regional planners to change their places of production. While industries may be induced to move to a certain region by means of subsidies, tax incentives or other regional policy instruments, it is even more difficult for policy makers to reduce the activities of industries already located in the region, if such reduction is commanded by the goal of improved industrial diversification. The empirical results show that potential efficiency gains from diversification cannot be

realized if industrial income levels can only be increased, but not reduced. This limits the usefulness of portfolio analysis, at least for short-term industrial diversification planning.

Additionally, it is assumed that income from agriculture, forestry and fishing and mining cannot be increased directly, due to natural resource restrictions of a metropolitan area. The same is assumed for service industries so that only indirect and induced changes in their income levels are permitted. Total, i.e., direct, indirect and induced, changes in income are also bounded to take into account possible limits to local industries' growth potential.

Maximizing portfolio return may not result in higher income levels. In fact, it turns out for Chicago, that higher portfolio returns are associated with lower income levels. One possible explanation for this may be that industries with positive growth rates are relatively small in size. To avoid this inconsistency of two policy goals, total income is bound to be at least at the base year-income level.

An efficiency frontier is derived for different values of λ , representing different risk preferences, ranging from 1 (lowest level of risk aversion) to 10,000 (strong preferences for avoiding risk). The quadratic programming problems are solved with GAMS, whose solver for nonlinear optimization problems uses a combination of a reduced-gradient and a quasi-Newton algorithm (Brooke et. al. 1992).

Figure 1 shows two efficiency frontiers based on Model 1 as well as the position of Chicago's predicted industrial mix in 2010 in the return-risk space. One frontier is estimated without any restrictions on the policy variables or income changes, while such restrictions are imposed in the estimation of the second frontier: Positive direct changes cannot exceed 1995 income levels, while negative changes are constrained to 50% of 1995 income levels; total changes in income are bound to be below 400% of 1995 income levels, and the level of total income has to be greater than or equal to the predicted income in 2010. While the constraint on total income change is derived from the observation that over several past 15 year periods no sector's income grew more than 400%, the restrictions on δ are chosen arbitrarily. Future research must explore ways to determine these bounds based on empirical facts rather than assumptions. This is even more important since Figure 1 shows that the introduction of bounds into the model significantly diminishes the potential efficiency gains from industrial diversification. These gains can be evaluated, for example, by measuring the vertical distance between the position of the predicted industrial portfolio and the associated

point on the frontier above it. Accordingly, given the same level of risk, efficient diversification of Chicago's industrial base can yield an increase in the portfolio return (which is the average income growth rate) of 2.3 percentage points for the unbounded frontier, but only an increase of 0.3 percentage points for the bounded frontier. These constraints also makes the efficiency frontier much shorter, so that the maximum achievable return is lower and the minimum achievable risk higher. If the bounds become even more stringent, e.g., if negative direct income changes are ruled out, the efficiency gains become negligible and the frontier may reduce to a single point. The implication of this is that regional portfolio theory is more appropriate for long-term planning than short-term policy design, at least if return considerations are not excluded.⁸

A closer look at the sectoral patterns along the frontier helps to explain why regional portfolios exhibit a return-risk trade-off. The results show that if risk aversion is low, the regional income generation is concentrated on a few sectors, namely those with the highest predicted growth rates. Strong risk aversion results in a more even industrial distribution and therefore lower returns, since more weight is given to industries with negative growth. For the efficiency frontier to have a positive slope, it is therefore not required that industries with high returns are riskier than industries with low returns.

Since all industries are linked to each other, in order to obtain the optimal industrial portfolio, a complex mix of policy impulses is needed. When the solutions to the bounded model are analyzed, it turns out that none of the industries with positive upper bounds and negative lower bounds for δ are subjected to positive shocks for all values of λ , but fourteen industries are persistently subjected to negative impulses. For three industries (tobacco, petroleum and rubber and plastic) the model recommends positive stimulation for low λ , but negative stimulation for high λ , suggesting that these industries contribute indirectly to high portfolio return. Seven industries' income levels (chemicals, stone, clay and glass, instruments, miscellaneous manufacturing, transportation, communications, and utilities) are directly increased only for large λ , implying that they indirectly lower portfolio return.

Introducing policy impulses for $\lambda=1$ and $\lambda=200$ results in changes in the sectoral mix of Chicago's economy. If high returns are preferred, the sectoral income distribution changes in favor of the industries whose predicted growth rates are positive:

⁸ Conroy (1974), even though he conceptually deals with both return and risk considerations,

chemicals, instruments, transportation, communications and utilities. When risk considerations prevail, many of the shares of industries with negative growth rates are increased as well, while the service industry loses income to reduce sectoral income concentration. This result, however, may be affected by the high level of aggregation for service sectors. The income shares of forestry and fishing, construction, lumber and wood and transportation equipment (and most of the service sectors, probably due to the restriction that their income levels cannot be directly changed) always decline, independent of the level of risk aversion. This strongly suggests that the activities of these four sectors, in particular the activities of the construction industry and forestry and fishing, whose growth rates are positive, are relatively risky in terms of income growth fluctuations.

Before estimating Model 2, the efficient portfolios are evaluated with respect to the emissions they may generate. This involves two important assumptions, which could be relaxed in the future: 1992 sectoral emissions are divided by 1992 sectoral income levels; these income-pollution coefficients are assumed to remain unchanged in the future, which ignores, besides other factors (see Fritz 1996b) the possibility of technological change. Furthermore, emissions are assumed to be proportional to income. Despite these severe assumptions, it can be expected that industries with relatively high 1992 pollution levels will also generate relatively more pollution in the future.

Observing emission levels of five air pollutants for the portfolios along the bounded frontier derived from Model 1 shows that low risk portfolios generate more emissions than high return portfolios. It follows therefore that pollution constraints included in the portfolio model will affect the low risk section of the frontier to a greater degree than the section with high return portfolios. Figure 2 presents the bounded efficiency frontier of Model 1 and an efficiency frontier which is estimated subject to a 50% reduction of predicted 2010 emission levels (Model 2). The frontier has shifted to the southeast and is much shorter than the pollution unconstrained frontier. Optimal industrial diversification in this case cannot accomplish significant risk reduction. This suggests that a pollution-risk tradeoff, rather than a return-pollution tradeoff, exists in Chicago.

The consequences of these emissions constraints in terms of the optimal sectoral income mix are revealed when changes in income shares with respect to the predicted shares in 2010 are compared. It is evident that many of the manufacturing industries

lose income shares under Model 2, while they gained income shares under Model 1. Transportation equipment and miscellaneous manufacturing receive higher shares, independent of risk preferences, as do some of the service industries and, unexpectedly, utilities. Wholesale and retail and hotels, personal and business services, two industries with very high indirect pollution, have their shares significantly reduced.

Since setting arbitrary pollution constraints is not compatible with a market-based approach to environmental economics, Model 3 discounts expected returns from industrial activities and sectoral income levels by the value of damages caused by industrial air pollution. Upper bounds of marginal damages from atmospheric emissions for particulate matter, nitrogen oxides and sulfur oxides estimated by Repetto (1990) are used here. Since estimates for volatile organic compounds and carbon monoxides are not available, the marginal value of their damages is assumed to be equal to the average of the values for the other three pollutants⁹. Applying the methodology outlined in the previous section, a new efficiency frontier, based on the bounds of Model 1, is estimated. Pollution damages account for up to 1.89% of total industrial income in Chicago and for up to 88% of the income of primary metals and 71.5% of the petroleum sector's income. Figure 3 shows that, as expected, the frontier shifts to the southeast, reducing the potential for efficiency gains. In addition, Chicago's predicted position in the return-risk space in 2010 shifts to the northeast (higher return at larger risk) if industrial income is discounted for pollution damages. The composition of the portfolios along the adjusted frontier does not change much, especially for a small λ : in the case of high risk aversion, fabricated metals and electrical machinery have increased income shares, while many other manufacturing sectors, including, as expected, petroleum and primary metals, have lower ones. These rather small effects can be explained by the fact that only some of the damages of airborne emissions are included, but other damage categories, like climate effects, are not. Most importantly, damages from other forms of pollution (toxic air pollution, water, land, noise pollution) are excluded as well. A more complete damage evaluation will certainly cause more dramatic shifts of the frontier.

Applying Model 4 efficiency frontiers for several time periods are estimated. It is designed to include more realistic assumptions about a policy makers' decision problem. A regional industrial diversification plan will probably attempt to gradually improve the industrial base over several years, and, if externalities are an issue, may

define some emission targets to be accomplished in the future. Additionally, the restrictions for changing sectoral income shares will be very limiting. Model 4 is estimated based on a plan that starts in 1995 and wants to improve industrial diversification over three periods: 1995-2000, 2000-2005 and 2005-2010. No explicit constraints on total industrial emissions are set for the first two periods, but a 20% reduction of 1995 emission levels has to be accomplished by the end of the planning horizon.¹⁰ Positive policy impulses are restricted to 33.3% of the income in the previous period, negative impulses to 16.6% and total income change to 133.3%. These bounds are equivalent to the ones applied earlier in Model 1, but reflect the fact that the planning is carried out over three shorter periods instead of one longer period. Sectoral income is assumed to grow at the rates predicted by CREIM and the sum of these sectoral income levels constitutes the lower bound for income changes, so that increasing returns at the cost of lowering income levels is precluded.

Figure 4 shows the efficiency frontiers for each of the three periods. Due to predicted sectoral growth patterns, which gradually reduce the share of industries with negative growth rates (and thereby lead to a more concentrated sectoral distribution of income), the frontiers shift to the northeast, diminishing the potential for risk reduction and increasing possible gains from higher returns. However, due to the tight bounds and the emissions constraint, the returns for low and high risk aversion differ only by approximately 6.0 to 7.3%, and the returns between time periods by 9.5 to 10.9%. This again indicates the sensitivity of potential efficiency gains from industrial diversification to assumptions about the ability of regional policy to change sectoral income shares. The solution of Model 4 is also influenced by the assumption that 'utility' (i.e., the difference between portfolio return and portfolio risk) is maximized over the whole planning horizon, not merely for the last period.

For policy purposes, it may also be useful to assess the effects of increases in only one sector's income, keeping the income levels of all other industries constant. The CREIM multiplier table is applied to estimate the marginal income effects. New sectoral weights are computed and used to estimate changes in portfolio return and risk. Additionally, the induced increases in total emissions are recorded. An industry is considered polluting if a small change in its income level leads to an above-average increase in total emissions, and is considered clean otherwise. The results suggest that

⁹ It is appropriate at this point to quote Repetto (1990, p. 9), who refers to the imprecise estimates of pollution damages when he writes: 'It is better to be roughly right than precisely wrong'.

¹⁰ Higher abatement targets resulted in infeasible model solutions.

the majority of marginal sectoral income changes reduces both risk and return and leads to below-average increases in emissions. The income effects of construction and agriculture result in higher risk but lower returns, which suggests that their income shares should be reduced. For forestry and fishing, as well as finance and insurance, hotels, personal and business services and amusements, the income effects increase both risk and return. Four industries are considered to be polluting: food, petroleum, primary metals and utilities.

5 POLICY IMPLICATIONS AND EVALUATION OF REGIONAL PORTFOLIO ANALYSIS

Not knowing to what extent regional policy makers can attract new firms and induce existing firms to either increase or reduce their activity levels, explicit policy recommendations from a regional portfolio analysis are difficult to infer. As the simulations illustrated in the previous section clearly show, the determination of the right bounds has significant effects on the potential for efficiency gains. Nevertheless, it is feasible to derive more general policy implications based on some trends revealed by the model simulations.

The more risk averse a region's decision makers are, the more they should try to widen the industrial base and decrease sectoral concentration, even if this implies increasing the shares of industries that do not yield high returns or have negative returns. On the other hand, higher industrial growth can be achieved if industries with positive return are given incentives to increase their shares in total regional income, while the shares of industries with low or negative return are reduced. Even though these implications may seem quite obvious, it is less clear how the desired industrial mix can be achieved, given that industries are very much interdependent and policies directed towards the expansion of a high return sector, for instance, may at the same time increase the share of a low return industry. Consequently, the patterns of policy impulses emerging from the estimation of efficient portfolios often seem counterintuitive, where positive impulses are given to industries whose expansion does not seem suitable to accomplish the desired policy goal. This result strongly suggests that interindustry linkages have to be included in regional portfolio models, for doing otherwise may render the wrong directions for a useful diversification policy.¹¹

¹¹ This has also been noted by Jackson (1984) [and Hunt and Sheesley \(1994\)](#).

The models perform less well (in the sense that potential efficiency gains are significantly diminished) when policies are restricted to providing positive incentives to industries and decreasing an industry's level is ruled out. This may pose serious problems to regional policy makers, most of whose instruments are designed to encourage firms to locate in the region rather than make them leave. The analysis of marginal changes suggests that increasing only one sector's income can reduce risk but does not easily achieve higher return. Many of the efficiency gains are based on altering the industrial mix such in such a way that some industries are exposed to negative shocks and others to positive shocks. However, for this and other findings as well, it remains open if they apply to Chicago's industrial structure only, or have more general validity. Since for the majority of Chicago's industries negative growth rates are predicted, industrial diversification may yield different results if more growth industries are included in the portfolio. Gilchrist and St. Louis (1991, 1994), for instance, using a general equilibrium framework to analyze industrial diversification strategies for Saskatchewan, find several industries whose expansion increases return but decreases risk and therefore improve the region's welfare independent of risk preferences.

With respect to Chicago's industrial air pollution, a tradeoff between portfolio risk and emissions abatement is evident. Risk reduction is based on widening the industrial base. Consequently, the shares of many of the polluting industries have to increase. This is not the case if higher returns are the goal, since many of these industries have significantly negative growth rates. Not much additional insight is gained by estimating the frontier with growth rates discounted for pollution damages. To improve the analysis, it is essential to include more pollution types as well as damage categories. The imprecise nature of existing environmental evaluation methods poses another problem. The gap between upper and lower estimates of pollution damages is so wide, that policy recommendations based on those estimates are very unreliable. Nevertheless, the evaluation approach avoids setting arbitrary abatement targets.

Finally, the usefulness of regional portfolio theory shall be assessed, based on the literature review and empirical findings of this study. When Conroy (1974) first proposed the application of financial portfolio theory to the problems of optimal regional diversification, he restricted his empirical analysis to risk considerations and found that his methodology explained fluctuations in regional employment better than previously used methods. But risk is only one of the aspects a regional planner has to consider. Growth of income, employment or output ranks also high on the list of regional policy goals. Since financial portfolio theory deals with a risk-return tradeoff,

its regional counterpart must try to specify what the returns to regional industrial activities are. Finding the right measure is a key issue in determining the usefulness of this methodology for policy purposes. Two basic alternatives, levels of income or employment and growth rates, have been proposed in the literature and were discussed earlier in this paper. This study has used growth rates, since they are more consistent with the concept of returns to regional assets. Several problems have become evident: while the use of regional instead of national sectoral growth rates should principally account for the different characteristics of regions, especially their comparative advantages, this is not always the case. Additionally, the assumption that manipulating the sectoral weights will not affect sectoral growth rates, which are considered exogenous, seems unrealistic. If an industry's income weight is changed by the policymaker, its regional growth rate will most likely reflect those changes: an industry's increasing income share will be accompanied by more rapid growth of that industry and vice versa. Furthermore, over time a region's industrial structure will naturally, i.e. without policy intervention to change the industrial mix, shift towards industries with positive growth rates and away from industries with negative growth rates so that its portfolio return increases.

Another critical issue is related to the use of growth rates as indicators of regional welfare. The simulations of the previous section have shown that high levels of portfolio return, equivalent to high average regional growth, do not imply a high level of regional income or gross product. As mentioned above, for Chicago portfolios with high returns are associated with low levels of total regional income. Adding minimum levels of total income to the constraints of the portfolio optimization problem will further reduce the potential efficiency gains. Despite its relevance for regional policy applications, the potential tradeoff between income or employment maximization and the maximization of their growth rates has not been discussed in the regional portfolio literature.

Notwithstanding the many methodological problems, regional portfolio analysis should be included in the regional planners toolbox. The computation of risk and return in addition to putting existing portfolios in perspective to a frontier with efficient portfolios, are meaningful ways to assess a region's industrial structure and the consequences of industrial policies that might change this structure. It allows, for example, to find target portfolios closer to the frontier. Carrying out regional portfolio analysis without taking into account the links between different industries will lead to the wrong policy recommendations and should therefore be avoided. Specifying

unrealistically wide bounds will greatly overestimate the potential for efficiency gains. And finally, environmental constraints need to be included since pollution affects regional welfare, whose increase is after all the only purpose for doing this kind of analysis.

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APPENDIX

Model 1: Portfolio model with interindustry linkages.

$$\begin{aligned} & \underset{\delta_i}{\text{maximize}} \sum_i w_i R_i - \lambda(\tilde{w}' \Sigma \tilde{w}) \\ & \text{subject to} \\ & w_i = \frac{Y_i}{Y^{\text{tot}}} \\ & \sum_i w_i = 1 \\ & Y_i = B\tilde{\delta} + Y_i^{\text{base}} \\ & \delta_i^L \leq \delta_i \leq \delta_i^U; Y_i \leq Y_i^U; i = 1, \dots, n. \end{aligned}$$

Model 2: A pollution constraint is added to Model 1.

$$\sum_i Y_i c_i \leq \bar{P}$$

Model 3: Portfolio model with interindustry linkages and discounted returns, assuming a uniform shadow price for a pollutant independent of its source. Constraints are the same as in Model 1.

$$\underset{\delta_i}{\text{maximize}} \sum_i w_i R_i (1 - \mu c_i) - \lambda(\tilde{w}' \Sigma \tilde{w})$$

Model 4: Dynamic portfolio model with interindustry linkages and a pollution constraint to be met in the last period.

$$\begin{aligned} & \underset{\delta_i(t)}{\text{maximize}} \sum_t \sum_i w_i(t) R_i - \lambda(\tilde{w}'(t) \Sigma \tilde{w}(t)) \\ & \text{subject to} \\ & w_i(t) = \frac{Y_i(t)}{Y^{\text{tot}}(t)} \\ & \sum_i w_i = 1 \quad \forall t \\ & Y_i(t) = B\tilde{\delta}(t-1) + g_i(t-1)Y_i(t-1) \\ & \sum_i Y_i(T)c_i(T) \leq \bar{P}(T) \\ & \delta_i^L(t) \leq \delta_i(t) \leq \delta_i^U(t); Y_i(t) \leq Y_i^U(t); i = 1, \dots, n; t = 1, \dots, T. \end{aligned}$$

Additional notation:

δ_i is the policy variable for income changes in sector i

Y_i^{base} is the income level in sector i in the base period

Y^{tot} is total income or the sum of sectoral income

Σ is a $n \times n$ covariance matrix

B is a $n \times n$ income multiplier matrix

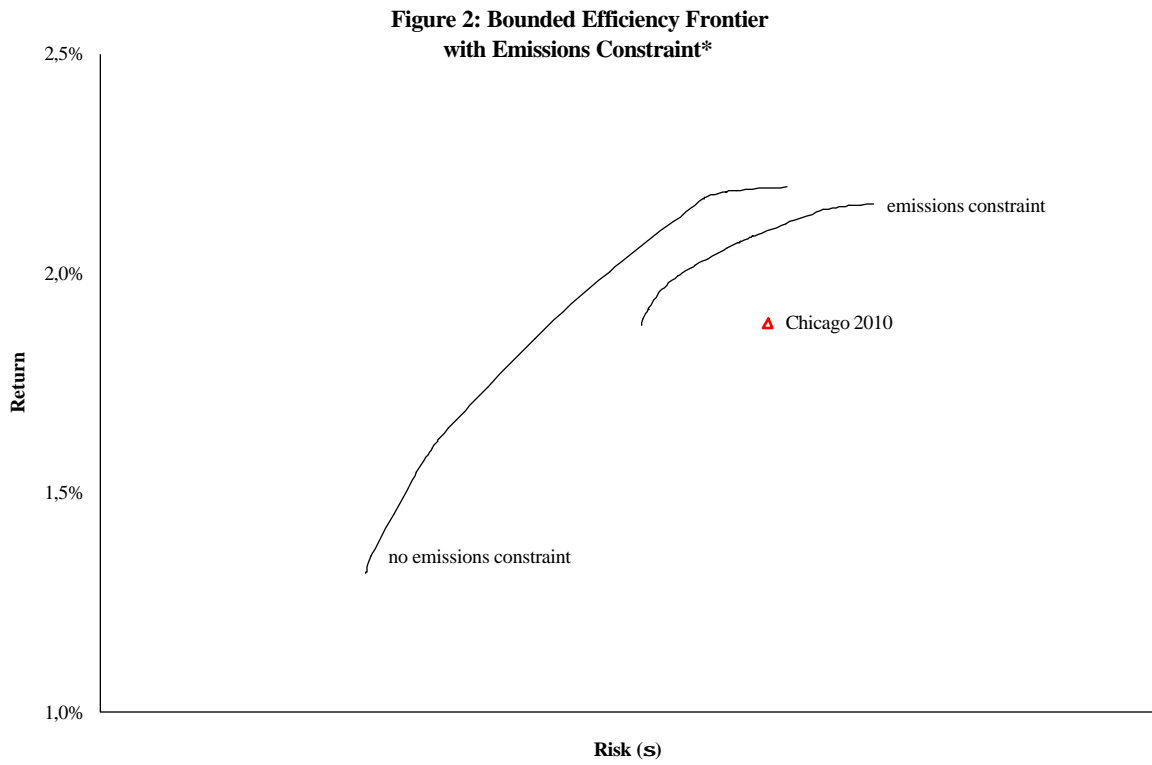
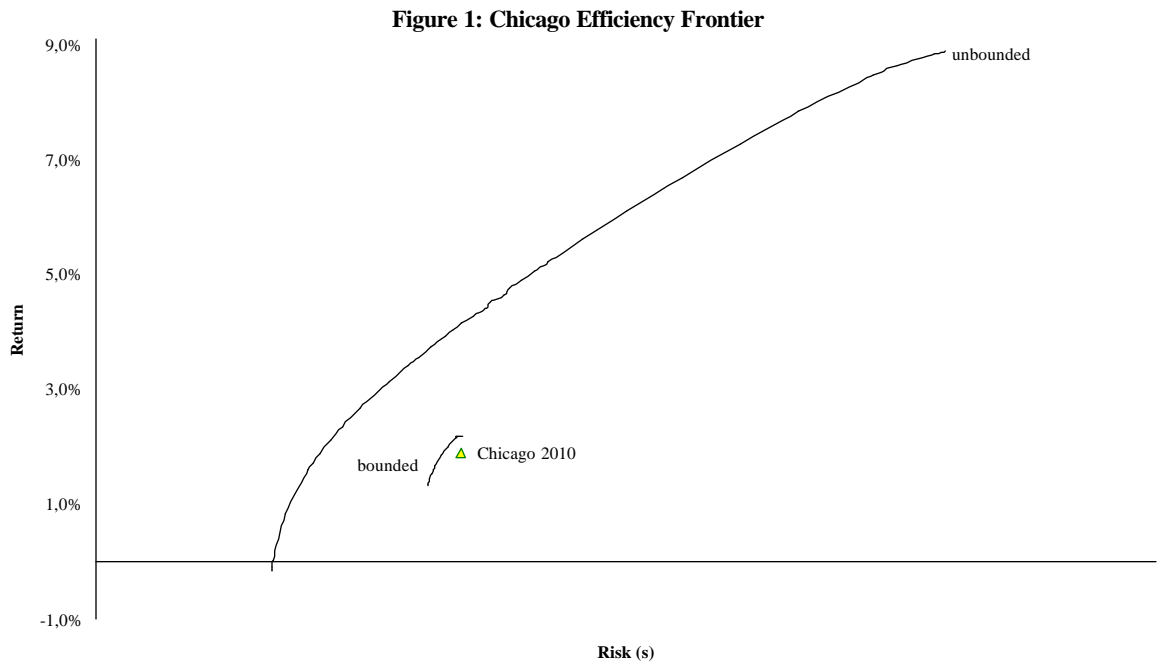
\bar{P} is the pollution standard or the upper bound on total emissions

λ is the risk preference parameter

g_i is the income growth rate of sector i

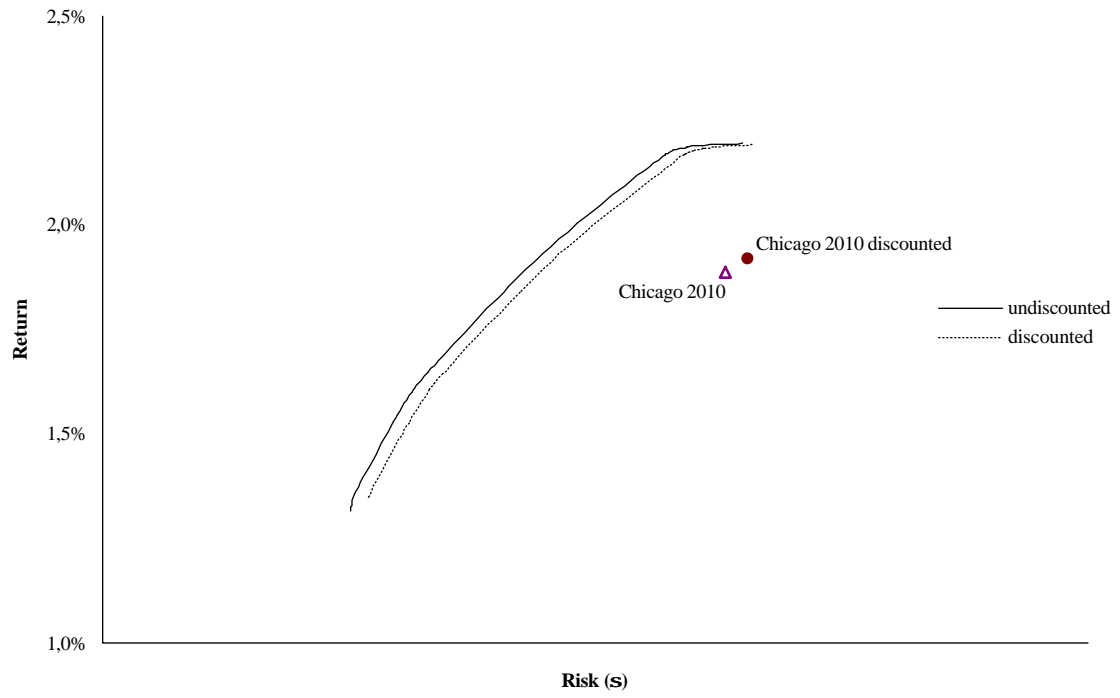
L, U are superscripts denoting lower and upper bounds of the variable

$\tilde{w}, \tilde{\delta}$ are $n \times 1$ column vectors



* 50% reduction in total emissions of each pollutant

**Figure 3: Efficiency Frontier
with Pollution Discounted Returns***



*Upper bound estimates of marginal pollution damages

Figure 4: Dynamic Efficiency Frontiers

