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The Optimum Solution of Quadratic programming problem By Wolfe's using two –phase Simplex method

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ABSTRACT

Quadratic programming (QP) solves the problem of maximizing a quadratic objective function subject to linear constraints. An alternative approach to Wolfe's method for Quadratic Programming problem (QPP) is proposed. It is a two –phase simplex method This method is simple to use when dealing with non-linear programming problems (NLPP) such as QPP. We developed a new strategy for solving a QPP using Wolfe's two –phase simplex method, which is based on an iterative procedure. When the new strategy is compared to the original Wolfe's two –phase simplex method in sense of computational process for solving NLPP, we found that the new method requires less or at most the same amount of iterations as Wolfe's two –phase simplex method. We discovered that the rule of selecting a pivot vector at the beginning of the process required more iterations for various NLPPs to achieve optimality. We choose the pivot vector in the first stage using the new rules mentioned. The technique yielded the best result after few iterations. The method produces efficient results.

Optimum Solution, Quadratic programming problem, Wolfe's method, two –phase, Simplex method and linear inequality constraints.

KEYWORDS

1. INTRODUCTION

The Quadratic Programming Problem (QPP) is a Non-Linear Programming Problem (NLPP) dealing with maximizing (or minimizing) the quadratic objective function with a set of linear inequality constraints.

The form of the General Quadratic Programming Problem (GQPP):

$$\text{Maximize } F = \sum_{J=1}^{N} \gamma_j x_j + \frac{1}{2}\sum_{J=1}^{N}\sum_{K=1}^{N} \gamma_{JK} x_J x_K$$

Subject to constraints:

$$\sum_{J=1}^{N} \alpha_{IJ} x_J \leq B_I$$

$where\ \gamma_{JK} = \gamma_{KJ}\ for\ all\ J\ and\ K\ ,and\ also\ B_I \geq 0$.

Let the Quadratic form $\sum_{J=1}^{N}\sum_{K=1}^{N} \gamma_{JK} x_J x_K$ be negative semi-definite.

We focus a method for fixing issues using common quadratic programming in this paper. These are quadratic objective function problems with optimization and linear constraint functions.

Algorithm Based on a simple modification of the simplex method, a simple method of quadratic programming converges in a certain number of iterations..The method was restricted to problem of convex quadratic function minimization and linear constraints of Philip Wolfe [1] and Dantzig [2]. The Dantzig-Wolfe approach is equivalent to the active set method, according to Fletcher [3]. Basic convex programming solvers can be updated to successfully terminate when solving a general Problem using a non-convex function, as have by Gill and Murray [4]. Gill and Murray successfully updated the active set method. Murray also developed an indefinite case algo-

rithm. Other types of methods are also feasible to solve the problem in general. Among these, the Ritter Cutting Plane methods Cottle and Mylander [5] . Complementarity pivoting methods to solve a wide range of Quadratic programming problems (even non-convex ones) Convex programming problems were solved using these methods Cottle and Dantzig [6] and recently Cottle [7]**.** Hashim [8] has shown the weakness of such methods with the same idea of pivoting for the same theory of pivoting. Keller's algorithm is one of them , a method by Van de Planne and Whinston [9] and also Lemke [10] . Khobragade [11] is an alternative method of a modified simplex solve by Wolfe's which is proposed for quadratic programming problems. Lokhande [12] Wolfe's modified simplex method was suggested as a suitable quadratic programming problem solution. We developed a new iterative procedure based on using Wolfe's modified simplex method, you may solve quadratic programming problems.

2. MATERIALS AND METHODS

To solve the mentioned QPP, below is another approach applying Wolfe's two-phase Simplex method Algorithm.

Step 1: Write all constraints in ≤ sign [13].

Step 2: adding slack variables to convert constraints into equality s_I^2 in the I^{th} constraints, where $1 \le I \le m$ and introduce s_{m+J}^2in the J^{th} non-negatively constraint, $1 \le J \le n$.

Step 3: Obtain Kuhn-Tucker condition .

$$L(x,s,\lambda,\mu) = F - \sum_{j=1}^{m} \lambda_i \left[\sum_{j=1}^{n} \alpha_{ij} x_j - \mathrm{B_i} + s_i^2 \right] - \sum_{j=1}^{n} \mu_{m_j} (-x_j + s_{m+j}^2)$$

$where\ x = (x_1, x_2, \dots, x_n), s = (s_1, s_2, \dots, s_{m+n}), \lambda = (\lambda_1, \lambda_2, \dots, \lambda_{m+n}),$

$\mu = (\mu_1, \mu_2, \dots, \mu_{m+n})$

Differentiate $L(x,s,\lambda,\mu)$ partially equal the first order derivative to zero in addition to the component x, s, λ and μ. From the resulting equations, derive the Kuhn-Tucker condition.

The necessary and sufficient conditions [3] are

$$\frac{\partial L}{\partial x} = 0 , \frac{\partial L}{\partial \lambda} = 0 , \frac{\partial L}{\partial \mu} = 0 , \frac{\partial L}{\partial s} = 0$$

Takes $s_i = s_i^2$ and derive the Kuhn-Tucker condition.

Step 4: Contruct the modified LPP artificial variables.

Add the fake non-negative variable $A_j, j = 1,2, \dots, n$ to the Kuhn-Tucker rules.

$$\sum_{K=1}^{N} \gamma_{JK} x_K - \sum_{I=1}^{M} \lambda_I \alpha_{IJ} + \mu_{M+J} + \gamma_J = 0 \ \ for\ J = 1,2, \dots, N$$

Construct an objective function $\mathrm{F}' = \mathrm{A}_1 + \mathrm{A}_2 + \cdots + \mathrm{A}_N$.

Step 5: Solve by simplex algorithm by two –phase method.

Use a new way to choose the maximum value of $z_j - c_j$ to find the pivot basic vector so as to arrive at the best solution to the LPP in the previous rule.

Let it be for some $j = k$, hence $\mathrm{y_k}$ enter into the basis. Select the outgoing vector by $\min\left(\frac{\mathrm{x_{Bi}}}{\mathrm{y_{ik}}}\right)$, let it be for some $i = r$.hence y_{rk} the pivot element.

If the same for two or more vectors then the vector with positive $z_j - c_j$ enters the basis.

If all $z_j - c_j = 0$, the optimum solution is obtained.

Step 6: The best solution for the specified QPP is the optimal idea obtained in step 5.

PROBLEMS

In the following we are going to illustrate the problem of the number of iterations in solving QPP are less (by method) than the solution obtained by existing method.

Take a new approach to solving the following QPP

PROBLEM [12]

Apply Wolfe's method to a quadratic programming problem.

$$\text{Maximize } \mathrm{Z} = 4x_1 + 6x_2 - 2x_1^2 - 2x_1x_2 - 2x_2^2$$

$$\text{subject to : } x_1 + 2x_2 \le 2, x_1, x_2 \ge 0$$

SOLUTION

Step 1: write all constraints in ≤ sign.

$$x_1 + 2x_2 \le 2$$

$$-x_1 \le 0$$

$$-x_2 \le 0$$

Step 2: Add slack variables s_i^2 to the i^{th} constraints for all constraints equal.

$$\text{Maximize } \mathrm{Z} = 4x_1 + 6x_2 - 2x_1^2 - 2x_1x_2 - 2x_2^2$$

$$\text{subject to : } x_1 + 2x_2 + s_1^2 = 2$$

$$-x_1 + s_2^2 = 0$$

$$-x_2 + s_3^2 = 0$$

$$x_i, s_i \geq 0$$

Step 3: obtain Kuhn-Tucker condition.

Build the Lagrangian function:

$$\begin{aligned} &L(x_1, x_2, s_1, s_2, s_3, \lambda_1, \mu_1, \mu_2) \\ &= (4x_1 + 6x_2 - 2x_1^2 - 2x_1x_2 - 2x_2^2) \\ &- \lambda_1(x_1 + 2x_2 + s_1^2 - 2) - \mu_1(-x_1 + s_2^2) \\ &- \mu_2(-x_2 + s_3^2) \end{aligned}$$

This is necessary and sufficient conditions:

$$\frac{\partial L}{\partial x_1} = 4 - 4x_1 - 2x_2 - \lambda_1 + \mu_1 = 0$$

$$4x_1 + 2x_2 + \lambda_1 - \mu_1 = 4$$

$$\frac{\partial L}{\partial x_2} = 6 - 2x_1 - 4x_2 - 2\lambda_1 - \mu_2 = 0$$

$$2x_1 + 4x_2 + 2\lambda_1 - \mu_2 = 6$$

$$\frac{\partial L}{\partial \lambda_1} = -(x_1 + 2x_2 + s_1^2 - 2) = 0$$

$$x_1 + 2x_2 + s_1^2 = 2$$

Take $s_i = s_i^2$ we have

KT:

$$\lambda_1 s_1 = 0\,, \mu_1 x_1 = 0\ \,, \mu_2 x_2 = 0 \text{ and } x_1, x_2, s_1, \lambda_1, \mu_1, \mu_2 \geq 0$$

Step 4: Build the modified LPP artificial variables.

$$\text{Maximize } Z = -A_1 - A_2$$

$$\text{subject to : } 4x_1 + 2x_2 + \lambda_1 - \mu_1 + A_1 = 4$$

$$2x_1 + 4x_2 + 2\lambda_1 - \mu_2 + A_2 = 6$$

$$x_1 + 2x_2 + s_1 = 2$$

$$\text{and } \lambda_1 s_1 = 0\,, \mu_1 x_1 = 0\ \,, \mu_2 x_2 = 0$$

Step 5: using a two-phase simplex get to for the solution.

Table 1: Initial table

	c_j	0	0	0	0	0	-1	-1	0		
	B_V	x_1	x_2	λ_1	μ_1	μ_2	A_1	A_2	s_1	Sol	Ratio
	$z_j - c_j$	-6 ↓	-6	-3	1	1	0	0	0	-10	
-1	A_1	4	2	1	-1	0	1	0	0	4 →	$\frac{4}{4} = 1$
-1	A_2	2	4	2	0	-1	0	1	0	6	$\frac{6}{2} = 3$
0	s_1	1	2	0	0	0	0	0	1	2	$\frac{2}{1} = 2$

Table 2: 1^{st} iteration

	c_j	0	0	0	0	0	-1	-1	0		
	B_V	x_1	x_2	λ_1	μ_1	μ_2	A_1	A_2	s_1	Sol	Ratio
	$z_j - c_j$	0	-3↓	$\frac{-3}{2}$	$\frac{-1}{2}$	1	$\frac{3}{2}$	0	0	-4	
0	x_1	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{-1}{4}$	0	$\frac{1}{4}$	0	0	1	2
-1	A_2	0	3	$\frac{3}{2}$	$\frac{1}{2}$	-1	$\frac{-1}{2}$	1	0	4	$\frac{4}{3}$
0	s_1	0	$\frac{3}{2}$	$\frac{-1}{4}$	$\frac{1}{4}$	0	$\frac{-1}{4}$	0	1	1→	$\frac{2}{3}$

Table 3: 2^{nd} iteration

	c_j	0	0	0	0	0	-1	-1	0		
	B_V	x_1	x_2	λ_1	μ_1	μ_2	A_1	A_2	s_1	Sol	Ratio

	$z_j - c_j$	0	0	-2 ↓	0	1	1	0	2	-2	
0	x_1	1	0	$\frac{1}{3}$	$\frac{-1}{3}$	0	$\frac{1}{3}$	0	$\frac{-1}{3}$	$\frac{2}{3}$	2
-1	A_2	0	0	2	0	-1	0	1	-2	2	1
0	x_2	0	1	$\frac{-1}{6}$	$\frac{1}{6}$	0	$\frac{-1}{6}$	0	$\frac{2}{3}$	$\frac{2}{3}$	-4

Table 4: 3^{rd} iteration

	c_j	0	0	0	0	0	-1	-1	0		
	B_V	x_1	x_2	λ_1	μ_1	μ_2	A_1	A_2	s_1	Sol	Ratio
	$z_j - c_j$	0	0	0	0	0	0	1	1	0	
0	x_1	1	0	0	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{6}$	0	$\frac{1}{3}$	
0	λ_1	0	0	1	0	$\frac{-1}{2}$	0	$\frac{1}{2}$	-1	1	
0	x_2	0	1	0	$\frac{1}{6}$	$\frac{-1}{2}$	$\frac{-1}{6}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{6}$	

Step 6: The optimal idea taken in **step 5** is the best solution for the given QPP.

$$\boldsymbol{x_1 = \frac{1}{3}}$$

$$\boldsymbol{x_2 = \frac{5}{6}}$$

Since all $z_j - c_j \geq 0$ thus it is optimal and solution $x_1 = \frac{1}{3}$, $x_2 = \frac{5}{6}$ and value of z is

$$\mathrm{Z} = 4x_1 + 6x_2 - 2x_1^2 - 2x_1x_2 - 2x_2^2 = \boldsymbol{\frac{25}{6}}$$

PROBLEM [14]

Apply Wolfe's method to a quadratic programming problem.

$$\text{Maximize } \mathrm{z} = 2x_1 + x_2 - x_1^2$$

$$\text{Subject to: } 2x_1 + 3x_2 \leq 6$$

$$2x_1 + x_2 \leq 4$$

$$x_1, x_2 \geq 0$$

SOLUTION

Step 1: write all constraints in ≤ sign.

$$2x_1 + 3x_2 \leq 6$$

$$2x_1 + x_2 \leq 4$$

$$-x_1 \leq 0$$

$$-x_2 \leq 0$$

Step 2: Add slack variables s_i^2 to the i^{th} constraints for all constraints equal.

$$\text{Maximize } \mathrm{z} = 2x_1 + x_2 - x_1^2$$

$$\text{subject to : } 2x_1 + 3x_2 + s_1^2 = 6$$

$$2x_1 + x_2 + s_2^2 = 4$$

$$-x_1 + s_3^2 = 0$$

$$-x_2 + s_4^2 = 0$$

$$x_i, s_i \geq 0$$

Step 3: obtain Kuhn-Tucker condition.

Build the Lagrangian function:

$$\begin{aligned} &L(x_1, x_2, s_1, s_2, s_3, s_4, \lambda_1, \lambda_2, \mu_1, \mu_2) \\ &= (2x_1 + x_2 - x_1^2) - \lambda_1(2x_1 + 3x_2 + s_1^2 - 6) \\ &- \lambda_2(2x_1 + x_2 + s_2^2 - 4) - \mu_1(-x_1 + s_3^2) \\ &- \mu_2(-x_2 + s_4^2) \end{aligned}$$

This is necessary and sufficient conditions:

$$\frac{\partial L}{\partial x_1} = 2 - 2x_2 - 2\lambda_1 - 2\lambda_2 + \mu_1 = 0$$

$$2x_1 + 2\lambda_1 + 2\lambda_2 - \mu_1 = 2$$

$$\frac{\partial L}{\partial x_2} = 1 - 3\lambda_1 - \lambda_2 + \mu_2 = 0$$

$$3\lambda_1 + \lambda_2 - \mu_2 = 1$$

$$\frac{\partial L}{\partial \lambda_1} = -(2x_1 + 3x_2 + s_1^2 - 6) = 0$$

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$$2x_1 + 3x_2 + s_1^2 = 6$$

$$\frac{\partial L}{\partial \lambda_2} = -(\ 2x_1 + x_2 + s_2^2 - 4) = 0$$

$$2x_1 + x_2 + s_2^2 = 4$$

Take $s_i = s_i^2$ we have

KT:

$\lambda_1 s_1 = 0\ , \mu_1 x_1 = 0\ \ , \mu_2 x_2 = 0$ and $x_1, x_2, s_1, \lambda_1, \mu_1, \mu_2 \geq 0$

Step 4: Build the modified LPP artificial variables.

Maximize $Z = -A_1 - A_2$

subject to : $2x_1 + 2\lambda_1 + 2\lambda_2 - \mu_1 = 2$

$3\lambda_1 + \lambda_2 - \mu_2 = 1$

$2x_1 + 3x_2 + s_1^2 = 6$

$2x_1 + x_2 + s_2^2 = 4$

and $\lambda_1 s_1 = 0\ , \lambda_2 s_2 = 0\ , \mu_1 x_1 = 0\ \ , \mu_2 x_2 = 0$

Step 5: solve by simplex algorithm by two –phase method.

Table 5: Initial table

	c_j	0	0	0	0	0	0	-1	-1	0	0		
	B_V	x_1	x_2	λ_1	λ_2	μ_1	μ_2	A_1	A_2	s_1	s_2	Sol	Ratio
	$z_j - c_j$	-2	0	-5↓	-3	1	1	0	0	0	0	-3	
-1	A_1	2	0	2	2	-1	0	1	0	0	0	2	$\frac{2}{2} = 1$
-1	A_2	0	0	3	1	0	-1	0	1	0	0	1→	$\frac{1}{3}$
0	s_1	2	3	0	0	0	0	0	0	1	0	6	
0	s_2	2	1	0	0	0	0	0	0	0	1	4	

Table 6: 1^{st} iteration

	c_j	0	0	0	0	0	0	-1	-1	0	0		
	B_V	x_1	x_2	λ_1	λ_2	μ_1	μ_2	A_1	A_2	s_1	s_2	Sol	Ratio
	$z_j - c_j$	0	0↓	−1	$\frac{-1}{3}$	0	$\frac{1}{3}$	1	$\frac{2}{3}$	0	0	$\frac{-1}{3}$	
0	A_1	2	0	0	$\frac{4}{3}$	-1	$\frac{2}{3}$	1	$\frac{-2}{3}$	0	0	$\frac{4}{3}$	
-1	λ_1	0	0	1	$\frac{1}{3}$	0	$\frac{-1}{3}$	0	$\frac{1}{3}$	0	0	$\frac{1}{3}$	
0	s_1	2	3	0	0	0	0	0	0	1	0	6→	$\frac{6}{3} = 2$
0	s_2	2	1	0	0	0	0	0	0	0	1	4	$\frac{4}{1} = 4$

Table 7 : 2^{nd} iteration

	c_j	0	0	0	0	0	0	-1	-1	0	0		
	B_V	x_1	x_2	λ_1	λ_2	μ_1	μ_2	A_1	A_2	s_1	s_2	Sol	Ratio

	$z_j - c_j$	-2↓	0	0	$\frac{-4}{3}$	1	$\frac{-2}{3}$	0	$\frac{5}{3}$	0	0	$\frac{-4}{3}$	
-1	A_1	2	0	0	$\frac{4}{3}$	-1	$\frac{2}{3}$	1	$\frac{-2}{3}$	0	0	$\frac{4}{3}\rightarrow$	
0	λ_1	0	0	1	$\frac{1}{3}$	0	$\frac{-1}{3}$	0	$\frac{1}{3}$	0	0	$\frac{-1}{3}$	
0	x_2	$\frac{2}{3}$	1	0	0	0	0	0	0	$\frac{1}{3}$	0	2	
0	s_2	$\frac{4}{3}$	0	0	0	0	0	0	0	$\frac{1}{3}$	1	2	

Table 8: 3^{rd} iteration

	c_j	0	0	0	0	0	0	-1	-1	0			
	B_V	x_1	x_2	λ_1	λ_2	μ_1	μ_2	A_1	A_2	s_1	s_2	Sol	Ratio
	$z_j - c_j$	0	0	0	0	0	0	1	1	0	0		
0	x_1	1	0	0	$\frac{2}{3}$	$\frac{-1}{2}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{-1}{3}$	0	0	$\frac{2}{3}$	
0	λ_1	0	0	1	$\frac{1}{3}$	0	$\frac{-1}{3}$	0	$\frac{1}{3}$	0	0	$\frac{-1}{3}$	
0	x_2	0	1	0	$\frac{-4}{9}$	$\frac{1}{3}$	$\frac{-2}{9}$	$\frac{-1}{3}$	$\frac{2}{9}$	$\frac{1}{3}$	0	$\frac{14}{9}$	
0	s_2	0	0	0	$\frac{-8}{9}$	$\frac{2}{3}$	$\frac{-4}{9}$	$\frac{-2}{3}$	$\frac{4}{9}$	$\frac{-1}{3}$	1	$\frac{10}{9}$	

Step 6: The best solution for the specified QPP is the optimal idea obtained in **step 5**.

$$x_1 = \frac{2}{3}$$

$$x_2 = \frac{14}{9}$$

Since all $z_j - c_j \geq 0$ thus it is optimal and solution $x_1 = \frac{2}{3}$, $x_2 = \frac{14}{9}$ and value of z is

$$z = 2x_1 + x_2 - x_1^2 = \frac{22}{9}$$

3. RESULTS AND DISCUSSION

The first table seen above displays Initial table, we make x_1 as the entering vector in the basis and leave A_1 in table 2, we make x_2 as the entering vector in the basis and leave s_1 in table 3, and since all $Z_j - C_j \geq 0$, an ideal solution has been found in three iterations. As a result, the best solution in Table 4 is $x_1 = \frac{1}{3}$, $x_2 = \frac{5}{6}$, and maximum $Z = \frac{25}{6}$. According to Table 5, In the initial table, we make λ_1 as the entering vector in the basis and leave A_2 in table 6, and we make x_2 as the entering vector in the basis and leave s_1 in table 7. A perfect solution has been found after three iterations because all $Z_j - C_j \geq 0$ are 0. The optimal solution is as follows: $x_1 = \frac{2}{3}$, $x_2 = \frac{14}{9}$ and maximum $Z = \frac{22}{9}$ in table 8.

The solution satisfies to the constraint on Lagrangian multipliers and the optimality requirement.

To find an optimal solution, use Matlab. Wolfe's two-phase Simplex method.

4. CONCLUSION

Wolfe's method to solve quadratic programming problems has an alternative method that has been deduced. Since there are so many non-linear programming applications. However, there is still a viable method for resolving generic NLPP.This method helps save time when used to numerical problems.

The two –phase technique yielded the best result after three iterations. The method presented an efficient and good results with less time simplifying Numerical Problems. Future work concerns Solving Quadratic Programming Problem Using Stable Factorization.

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