The SYMPHONY Callable Library for Mixed-Integer Linear Programming

A Tutorial

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Outline of Talk

- Introduction to SYMPHONY
- Using SYMPHONY as a black box solver
  - Downloading and compiling
  - Using from the command line
  - Using the interactive shell
- Using the SYMPHONY callable library
  - C API
  - C++/OSI API
- Developing custom solvers using the SYMPHONY framework
  - Callback API
  - Example
- Advanced Features
  - Sensitivity analysis
  - Warm starting
  - Bicriteria solve
  - Parallel Execution

Brief Overview of SYMPHONY

- SYMPHONY is an open-source software package for solving and analyzing mixed-integer linear programs (MILPs).
- SYMPHONY can be used in three distinct modes.
  - Black box solver: Solve generic MILPs (command line or shell).
  - Callable library: Call SYMPHONY from a C/C++ code.
  - Framework: Develop a customized black box solver or callable library.
- Fully integrated with the Computational Infrastructure for Operations Research (COIN-OR) libraries.
- Advanced features
  - Sensitivity analysis
  - Warm starting
  - Bicriteria solve
  - Parallel Execution
- This talk based on version 5.1 (unreleased, but in CVS)

Algorithmic Features

- Core solution methodology is a state of the art implementation of the branch, cut, and price algorithm.
- Default search strategy is a hybrid depth-first/best-first strategy.
- Built-in strong branching mechanism.
- Uses the primal heuristic of CBC.
- Cuts can be generated with COIN-ORs Cut Generation Library.
  - Clique
  - Flow Cover
  - Gomory
  - Knapsack Cover
  - Lift and Project
  - Mixed Integer Rounding
  - Odd Hole
  - Probing
  - Simple Rounding
  - Two-slope MIR

What's Available

- Packaged releases from www.branchandcut.org
- Current source at CVS on www.coin-or.org.
- An extensive user's manual on-line and in PDF.
- A tutorial illustrating the development of a custom solver step by step.
- Configuration and compilation files for supported architectures
  - Single-processor Linux, Unix, or Windows
  - Distributed memory parallel (PVM)
  - Shared memory parallel (OpenMP)
- Source code for SYMPHONY solvers.
  - Generic MILP
  - Multicriteria MILP
  - Multicriteria Knapsack
  - Traveling Salesman Problem
  - Vehicle Routing Problem
  - Mixed Postman Problem
  - Set Partitioning Problem
  - Matching Problem
  - Network Routing

Downloading

- Three ways to get the SYMPHONY source
  - Download the latest packaged release from `www.branchandcut.org`.
  - Download from the COIN CVS server at `www.coin-or.org`.
    - Windows: Use WinCvs to check out the `SYMPHONY` module from `:pserver:anonymous@www.coin-or.org:/home/coin/coincvs`
    - Unix/Linux: `cvs -d :pserver:anonymous@www.coin-or.org:/home/coin/coincvs checkout SYMPHONY`
  - Download a tarball from `www.coin-or.org`
- Other software you may need
  - Other COIN libraries (not required, but highly recommended):
    - Osi: To interface with SYMPHONY or the underlying LP solver.
    - Clp: To use as the underlying LP solver.
    - Cgl: To generate cutting planes,
    - Coin: To support above libraries (utilities).
    - Win: To compile COIN under Windows.
  - GLPK: To read GMPL files or use as the underlying LP solver.
  - Some other third-party LP solver.

Building

- If using COIN, unpack source in the COIN root directory.
- Otherwise, unpack it anywhere.
- Unix/Linux
  - Modify `SYMPHONY/Makefile`.
    * Set architecture.
    * Choose LP solver.
    * Set paths to other software packages.
  - Type `make` in the `SYMPHONY` directory.
- Windows
  - Using `nmake`
    * Modify the `SYMPHONY\WIN32\sym.mak` file as in Linux.
    * Type `nmake /f sym.mak` in the `SYMPHONY` directory.
  - Using MSVC++ 6.0
    * Open the workspace file `SYMPHONY\WIN32\symphony.dsw`.
    * Choose the LP solver and set the paths to other libraries.
    * Build the `symphony` project.

Using the Black Box Solver

- Read and solve a model in MPS format:
  - Linux/Unix: `bin.$(ARCH)/$(LP_SOLVER)/symphony -F sample.mps`
  - Windows: `WIN32\Debug\symphony.exe -F sample.mps`
- Read and solve a model in GMPL format:
  - Linux/Unix: `bin.$(ARCH)/$(LP_SOLVER)/symphony -F sample.mod -D sample.dat`
  - Windows: `WIN32\Debug\symphony.exe -F sample.mod -D sample.dat`
- SYMPHONY also has an interactive shell.
- SYMPHONY can also be used with FLOPC++, an open-source, object-oriented modeling environment similar to ILOG's Concert Technology.
- Setting parameters
  - Command-line parameters are set Unix style (to get a list, invoke SYMPHONY with `-h`.
  - To set other parameters specify a parameter file with `-f par.par`.
  - The lines of the parameter file are pairs of keys and values.
  - Parameters are listed in the user's manual.

Using the C Callable Library

- The SYMPHONY library is automatically built along with the executable.
  - Unix/Linux: Located in the `lib.$(ARCH)/$(LP_SOLVER)/` directory.
  - Windows: Located in the `WIN32\Debug` directory.
- Primary subroutines
  - `sym_open_environment()`
  - `sym_parse_command_line()`
  - `sym_load_problem()`
  - `sym_find_initial_bounds()`
  - `sym_solve()`
  - `sym_mc_solve()`
  - `sym_warm_solve()`
  - `sym_close_environment()`
- Auxiliary subroutines
  - Accessing and modifying problem data
  - Accessing and modifying parameters
  - User callbacks

Implementing a Basic MILP Solver with the C API

- Using the callable library, we only need a few lines to implement a solver.
- The file name and other parameters are specified on the command line.
- The code is exactly the same for all architectures, even parallel.
- Command line would be

```
symphony -F model.mps
```

```
int main(int argc, char **argv)
{
   sym_environment *env = sym_open_environment();
   sym_parse_command_line(env, argc, argv);
   sym_load_problem(env);
   sym_solve(env);
   sym_close_environment(env);
}
```

Using the OSI Interface

- The COIN-OR Open Solver Interface is a standard C++ class for accessing solvers for mathematical programs.
- Each solver has its own derived class that translates OSI calls into those of the solver's library.
- For each method in OSI, SYMPHONY has a corresponding method.
- The OSI interface is implemented as wrapped C calls.
- The constructor calls `sym_open_environment()` and the destructor calls `sym_close_environment()`.
- The OSI `initialSolve()` method calls `sym_solve()`.
- The OSI `resolve()` method calls `sym_warm_solve()`.
- To use the SYMPHONY OSI interface, simply make the SYMPHONY OSI library.

Implementing a Basic MILP Solver with the OSI Interface

- Below is the implementation of a simple solver using the SYMPHONY OSI interface.

- Again, the code is the same for any configuration or architecture, sequential or parallel.

```
int main(int argc, char **argv)
{
   OsiSymSolverInterface si;
   si.parseCommandLine(argc, argv);
   si.loadProblem();
   si.branchAndBound();
}
```

Using the SYMPHONY Framework to Develop a Custom Solver

- Advanced customization is performed using the user callback subroutines.
- There are more than 50 callbacks the can be implemented.
- The user can override SYMPHONY's default behavior in a variety of ways.
- Commonly used callback routines
  - `user_initialize_root_node()`
  - `user_display_solution()`
  - `user_create_subproblem()`
  - `user_find_cuts()`
  - `user_is_feasible()`
  - `user_select_candidates()`
  - `user_compare_candidates()`
  - `user_generate_column()`
  - `user_logical_fixing()`

Using the SYMPHONY Callbacks

- Function stubs for the callbacks are in the USER subdirectory.
- They are in files divided by functional module: Master/user_master.c, LP/user_lp.c, CutGen/user_cg.c, and CutPool/user_cp.c.
- Each callback returns either
  - USER_DEFAULT: Perform the default action (user did nothing)
  - USER_SUCCESS: User was successful in performing the function.
  - USER_ERROR: User encountered an error and could not perform the function.
- To use the callbacks, a new library is made including the callbacks.
  - Unix/Linux:
    * Type make in the USER subdirectory.
    * Executable will be bin.$(ARCH)/$(LP_SOLVER)/symphony
  - Windows:
    * Using nmake: Modify the USER\WIN32\user.mak file as before and type nmake /f user.mak.
    * Using MSVC++: Open the USER\WIN32\user.dsw file, modify settings as before, and build the user project.

Example Callback Routine

This code shows a custom solution display callback for a matching solver.

```
int user_display_solution(void *user, double lpetol, int varnum,
                          int *indices, double *values,
                          double objval)
{
   user_problem *prob = (user_problem *) user;
   int index;

   for (index = 0; index < varnum; index++){
      if (values[index] > lpetol) {
         printf("%2d matched with %2d at cost %6d\n",
                prob->match1[indices[index]],
                prob->match2[indices[index]],
                prob->cost[prob->match1[indices[index]]]
                [prob->match2[indices[index]]]);
      }
   }
   return(USER_SUCCESS);
}
```

Warm Starts for MILP

- To allow resolving from a warm start, we have defined a SYMPHONY warm start structure, based on the `CoinWarmStart` class.
- The class stores a snapshot of the search tree, with node descriptions including:
  - lists of active cuts and variables,
  - branching information,
  - warm start information, and
  - current status (candidate, fathomed, etc.).
- The tree is stored in a compact form by storing the node descriptions as differences from the parent.
- Other auxiliary information is also stored, such as the current incumbent.
- A warm start can be saved at any time and then reloaded later.
- The warm starts can also be written to and read from disk.
- Has the same look and feel as warm starting for LP.

Warm Starting Code (Parameter Modification)

- The following example shows a simple use of warm starting to create a dynamic algorithm.
- Here, the warm start is automatically save and reloaded.

```
int main(int argc, char **argv)
{
   OsiSymSolverInterface si;
   si.parseCommandLine(argc, argv);
   si.loadProblem();
   si.setSymParam(OsiSymFindFirstFeasible, true);
   si.setSymParam(OsiSymSearchStrategy, DEPTH_FIRST_SEARCH);
   si.initialSolve();
   si.setSymParam(OsiSymFindFirstFeasible, false);
   si.setSymParam(OsiSymSearchStrategy, BEST_FIRST_SEARCH);
   si.resolve();
}
```

Warm Starting Code (Problem Modification)

- The following example shows how to warm start after problem modification.

```
int main(int argc, char **argv)
{
   OsiSymSolverInterface si;
   CoinWarmStart ws;
   si.parseCommandLine(argc, argv);
   si.loadProblem();
   si.setSymParam(OsiSymNodeLimit, 100);
   si.initialSolve();
   ws = si.getWarmStart();
   si.resolve();
   si.setObjCoeff(0, 1);
   si.setObjCoeff(200, 150);
   si.setWarmStart(ws);
   si.resolve();
}
```

Example: Warm Starting

- Applying the code from the previous slide to the MIPLIB 3 problem p0201, we obtain the results below.
- Note that the warm start doesn't reduce the number of nodes generated, but does reduce the solve time significantly.

	CPU Time	Tree Nodes
Generate warm start	28	100
Solve orig problem (from warm start)	3	118
Solve mod problem (from scratch)	24	122
Solve mod problem (from warm start)	6	198

Bicriteria MILPs

- The general form of a bicriteria (pure) ILP is

$$
\begin{aligned}
\text{vmax}\ [cx, dx],& \\
\text{s.t.} \qquad\quad Ax &\le b, \\
x &\in \mathbb{Z}^n.
\end{aligned}
$$

- Solutions don't have single objective function values, but pairs of values called *outcomes*.
- A feasible $\hat{x}$ is called *efficient* if there is no feasible $\bar{x}$ such that $c\bar{x} \ge c\hat{x}$ and $d\bar{x} \ge d\hat{x}$, with at least one inequality strict.
- The outcome corresponding to an efficient solution is called *Pareto*.
- The goal of a bicriteria ILP is to enumerate Pareto outcomes.

Example: Bicriteria ILP

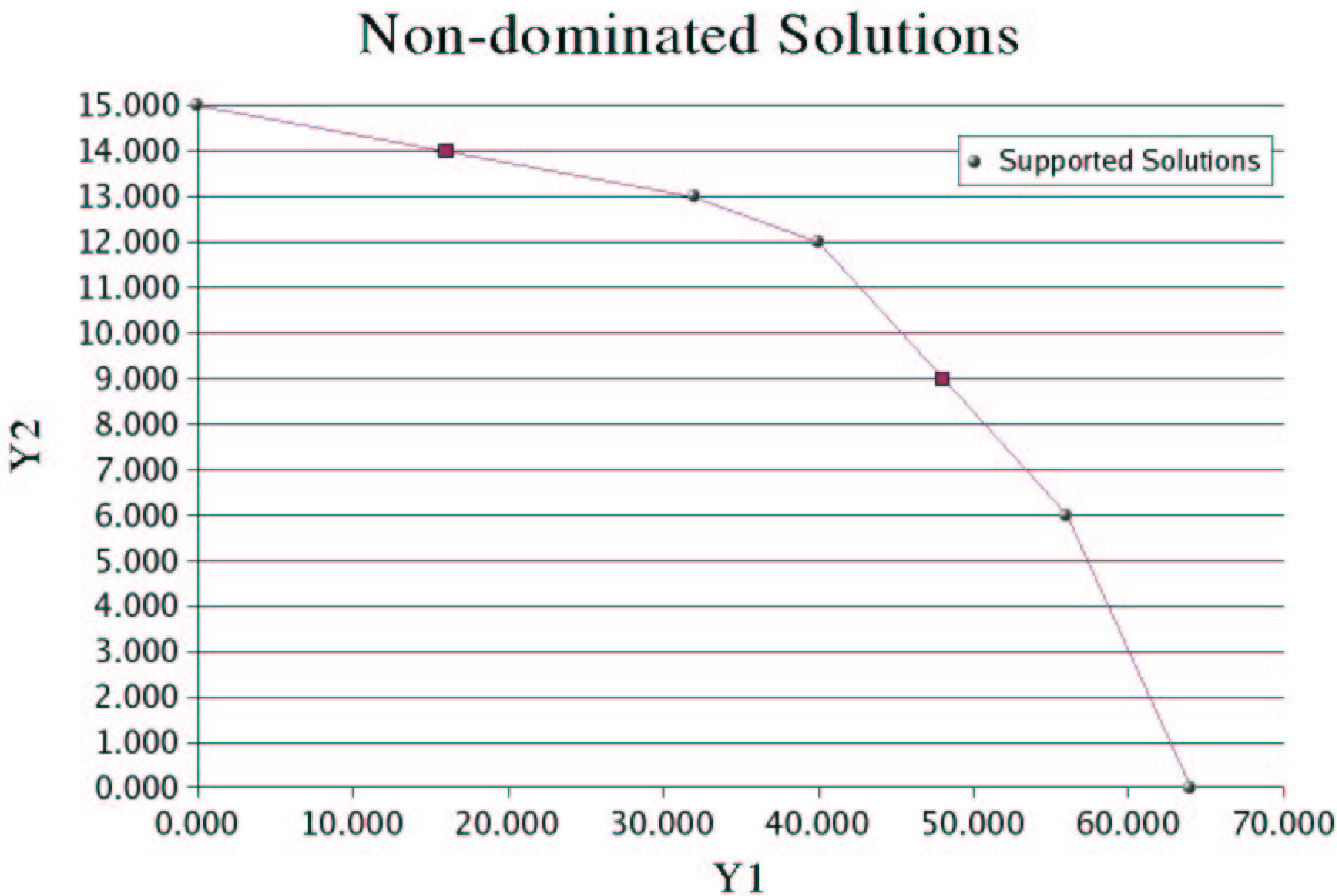
- Consider the following bicriteria ILP:

$$
\begin{aligned}
\text{vmax} \quad & [8x_1, x_2] \\
\text{s.t.} \quad & 7x_1 + x_2 \le 56 \\
& 28x_1 + 9x_2 \le 252 \\
& 3x_1 + 7x_2 \le 105 \\
& x_1, x_2 \ge 0
\end{aligned}
$$

- The following code solves this model.

```
int main(int argc, char **argv)
{
   OsiSymSolverInterface si;
   si.parseCommandLine(argc, argv);
   si.loadProblem();
   si.setObj2Coeff(1, 1);
   si.multiCriteriaBranchAndBound();
}
```

Example: Pareto Outcomes for Example

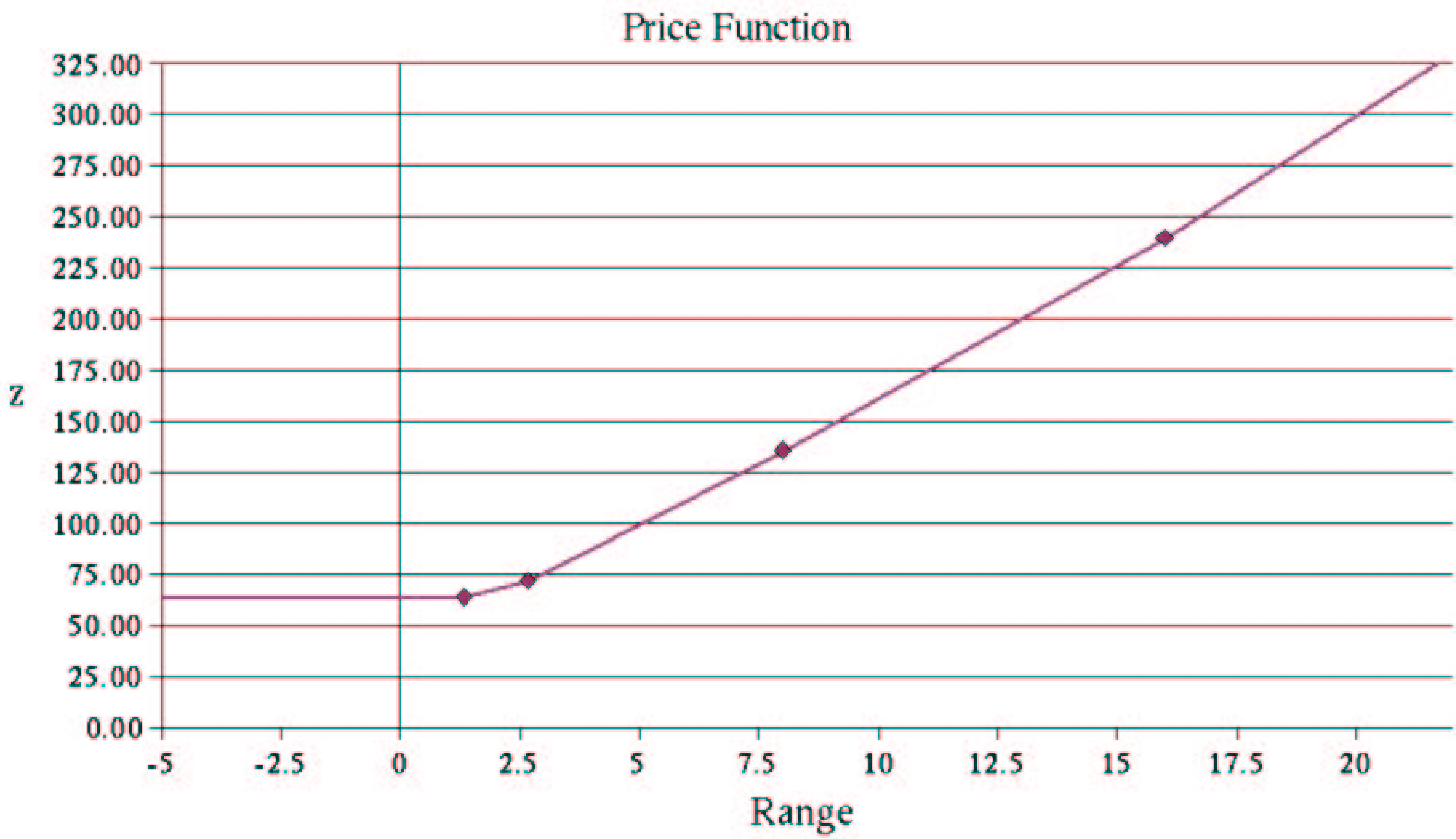


Example: Bicriteria Solver

By examining the supported solutions and break points, we can easily determine $p(\theta)$, the optimal solution to the ILP with objective $8x_1 + \theta$.

θ range	$p(\theta)$	x_1^*	x_2^*
$(-\infty, 1.333)$	64	8	0
$(1.333, 2.667)$	$56 + 6\theta$	7	6
$(2.667, 8.000)$	$40 + 12\theta$	5	12
$(8.000, 16.000)$	$32 + 13\theta$	4	13
$(16.000, \infty)$	15θ	0	15

Example: Graph of Price Function



Other Sensitivity Analysis

- SYMPHONY will calculate bounds after changing the objective or right-hand side vectors.

```
int main(int argc, char **argv)
{
   OsiSymSolverInterface si;
   si.parseCommandLine(argc, argv);
   si.loadProblem();
   si.setSymParam(OsiSymSensitivityAnalysis, true);
   si.initialSolve();
   int ind[2];
   double val[2];
   ind[0] = 4;   val[0] = 7000;
   ind[1] = 7;   val[1] = 6000;
   lb = si.getLbForNewRhs(2, ind, val);
   lb = si.getUbForNewRhs(2, ind, val);
}
```

Conclusion

- This has been a brief introduction to the capabilities of SYMPHONY.
- SYMPHONY can also be used in parallel, but this functionality has not been tested recently.
- We are currently in the process of further developing SYMPHONY's warm start and sensitivity analysis capabilities.
- We are also working on preprocessing and better primal heuristics.
- Please check `www.branchandcut.org` for future developments.
- Questions?