The Role of Wind in Enhancing UK Energy Diversity and Security

A Mean-Variance Portfolio Optimization of the UK Generating Mix

By

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A Mean-Variance Portfolio Optimization of the UK Generating Mix to 2020

- **Portfolio optimization locates generating mixes with lowest expected cost at every level of risk**
  - Risk is the year-to-year variability of technology generating costs
- **DTI projected generating mixes serve as a benchmark or starting point**
- **The optimal results indicate that compared to DTI target mixes, there exist generating mixes that cost no more, but have larger on-shore and offshore wind shares**

UK Target:
10% Renewable Energy Generation by 2010

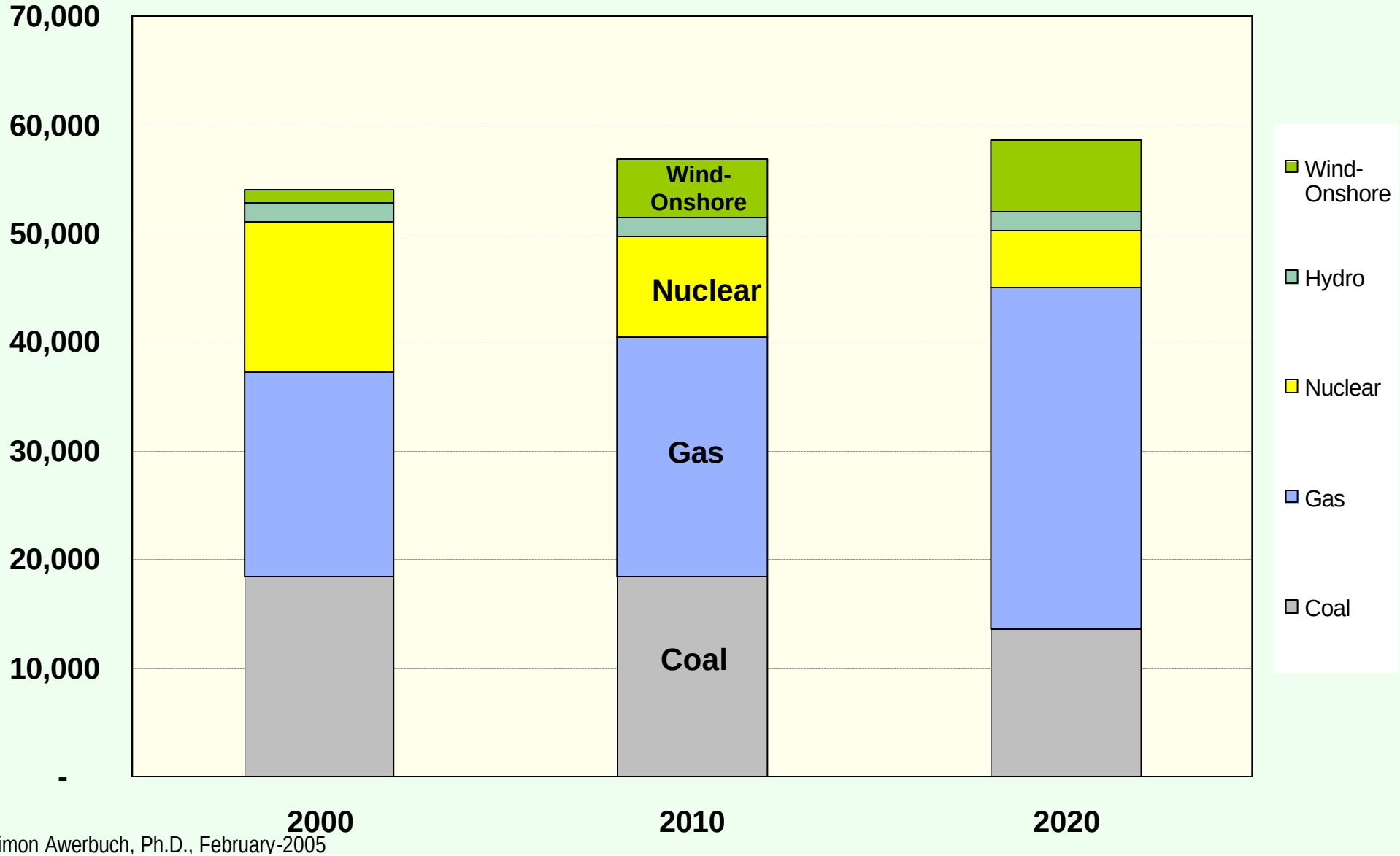
- **DTI** *Options for Low-Carbon Future:*
- **Wind targets attained in conjunction with sizeable increases in natural gas generation share**

Yearly Energy Production by Technology Type (TWh)
(Adapted from: DTI, *Options for Low Carbon Future*)

YEAR	2000		2010		2020	
	TWh	%	TWh	%	TWh	%
Coal	129	34%	129	33%	95	23%
Gas	148	39%	173	44%	248	61%
Nuclear	91	24%	61	16%	34	8%
Hydro	8	2%	8	2%	8	2%
Wind-Onshore	4	1%	19	5%	23	6%
Totals	**380**	**100%**	**390**	**100%**	**408**	**100%**

- **Maximum Wind Potential**
  - Onshore: 57 TWh - 19 GW
  - Offshore: 79 TWh - 25 GW

DTI *Options for Low-Carbon Future:* Projected MW Capacities



DTI *Options for Low-Carbon Future*: Projected MW Capacities

Current and Projected MW Capacity by Technology Type
(Adapted from: DTI, *Options for Low Carbon Future*)

YEAR	2000		2010		2020	
	MW	%	MW	%	MW	%
Coal	18,436	34%	18,436	32%	13,556	23%
Gas	18,798	35%	21,994	39%	31,507	54%
Nuclear	13,881	26%	9,254	16%	5,205	9%
Hydro	1,735	3%	1,735	3%	1,735	3%
Wind-Onshore	1,239	2%	5,431	10%	6,595	11%
Totals	**54,089**	**100%**	**56,850**	**100%**	**58,599**	**100%**

KWH Generating Costs Inputs (Constant Pence / Kwh) for Portfolio Optimization

Technology Cost Inputs (p/kWh)						
	DTI Technology Costs			Alternate Wind Costs		
	2000	2010	2020	2000	2010	2020
Old Gas	2.67	2.78	2.89			
Old Coal	3.33	3.33	3.33			
Old Nuclear	3.30	3.30	3.30			
Old Hydro	2.87	2.87	2.87			
Old Wind	2.68	2.68	2.68	6.00	6.00	6.00
New Gas	1.97	1.92	1.88			
New Coal	3.96	3.61	3.29			
New Nuclear	0.00	3.37	2.75			
New Onshore Wind	2.71	2.10	1.82	4.70	4.00	3.82
New Offshore Wind	-	3.58	3.58		5.00	4.50

Summary_tables_cost_Jan-05.xls

Understanding Risk

- **Portfolio optimization locates generating mixes with minimum cost and risk**
- **For each technology, risk is the year-to-year variability (standard deviation) of the three generating cost inputs: fuel, O&M and capital (construction period risk)**
  - Fossil fuel standard deviations are estimated from historic UK data
    - e.g. standard deviation for natural gas over the last 20 years is 0.23
  - Standard deviations for capital and O&M are estimated using proxy procedures (see Awerbuch and Berger, IEA, 2003)
- **The construction period risk for embedded technologies is 0.0**
- **'New' technologies are therefore riskier than embedded ones**
  - e.g. new coal is riskier than 'old' coal

Technology Risk Estimates (Standard Deviation)

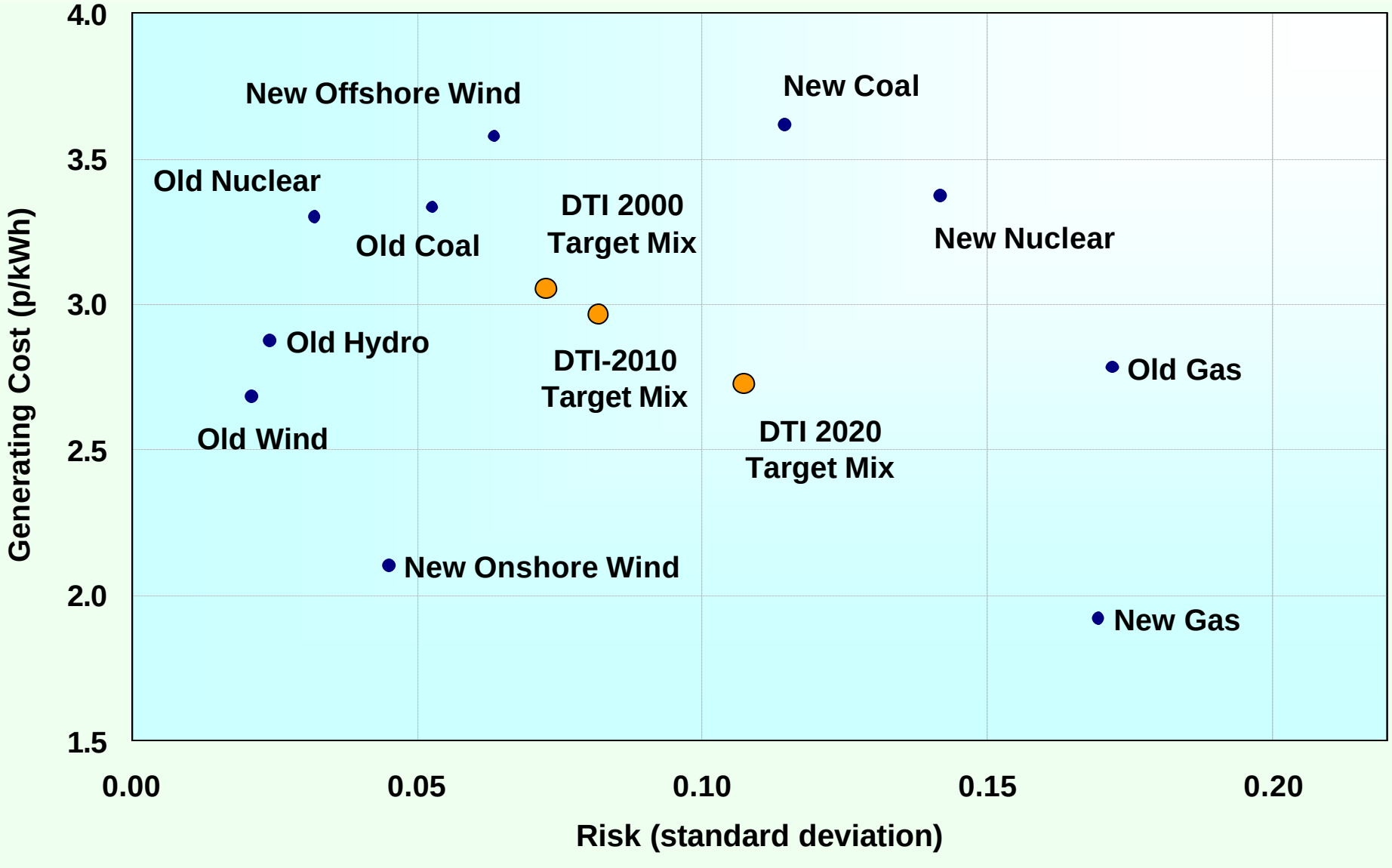
	Construction Period */	Fuel	Variable O&M	Fixed O&M
Gas	10.0%	23.0%	20.0%	8.7%
Coal	20.0%	12.8%	20.0%	8.7%
Nuclear	20.0%	9.5%	20.0%	8.7%
Hydro	20.0%	0.0%	20.0%	8.7%
Onshore Wind	5.0%	0.0%	20.0%	8.7%
Offshore Wind	7.5%	0.0%	20.0%	8.7%

***/ Construction period risk for existing (embedded) technologies is 0.0**

Total Risk for each generating technology is a weighted statistical summation of the component risks

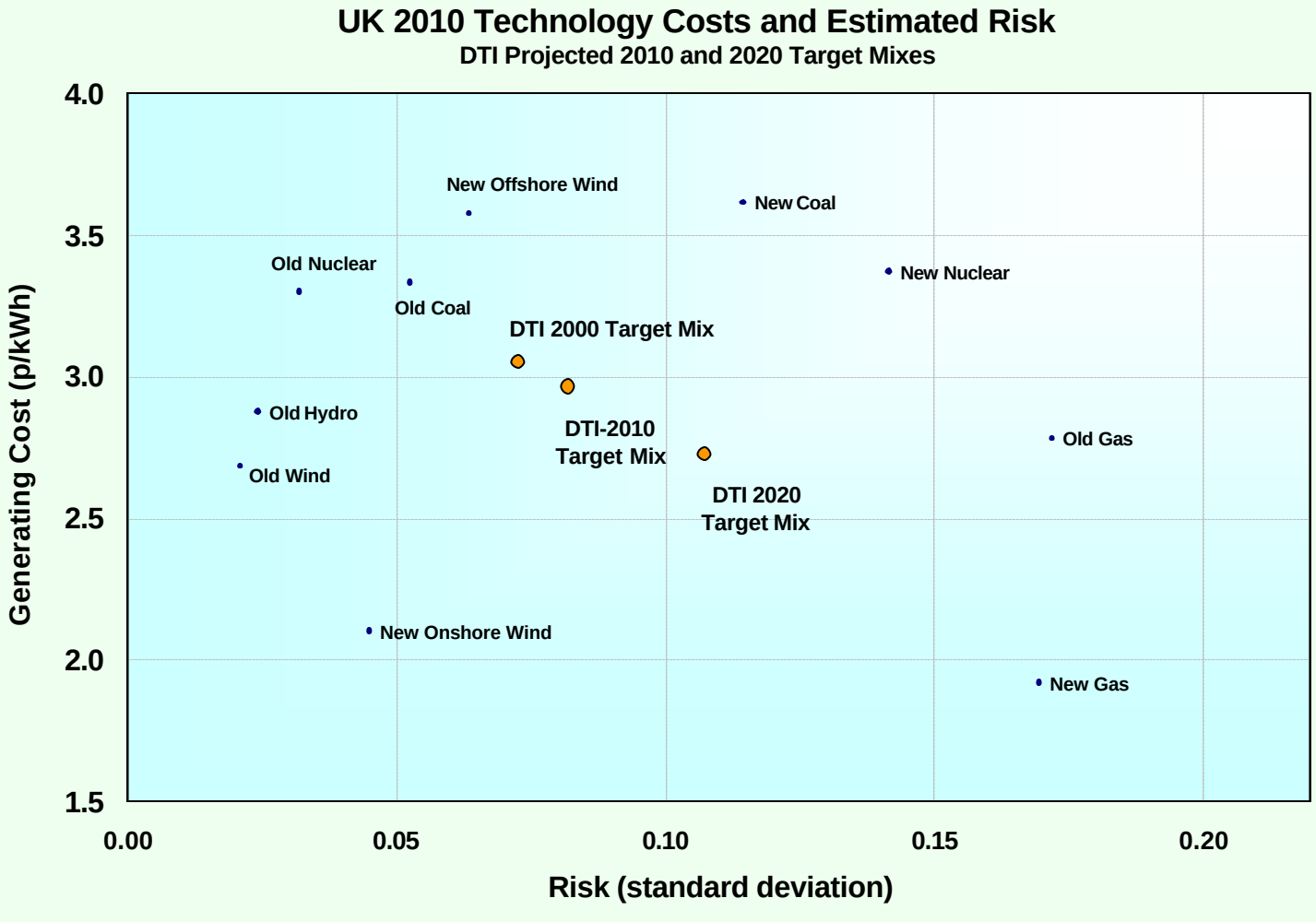
DTI 2010 Technology Costs and Estimated Risk

DTI Projected 2010 and 2020 Target Mixes (Constant GBP)



Projected UK Trends in Generating Cost-Risk

- **The move to larger natural gas shares significantly adds to portfolio risk**
  - Increases year-to-year expected generating cost volatility
- **Reduces Energy Diversity/ Security**
- **Of available new technologies, wind is ideally positioned to diversify the generating mix and reduce cost/risk**



Portfolio Optimization

- **Portfolio Optimization locates the lowest cost portfolio at every level of risk**
- **These optimal or *efficient* portfolios lie along the Efficient Frontier (EF)**
- **Portfolio Cost is the weighted average cost of the generating mix components**
- **For a two-technology generating mix:**
  - Expected portfolio cost is the weighted average of the individual expected costs of the two technologies:

$$\textbf{Expected Portfolio Cost} = E(C_p) = X_1 \bullet E(C_1) + X_2 \bullet E(C_2)$$

  - Where: X_1, X_2 are the proportional shares of the two technologies in the mix and $E(C_1)$ and $E(C_2)$ are the expected generating costs for those technologies

Portfolio Optimization (Continued)

- **Expected Portfolio risk, s_p, is a weighted average of the individual technology cost variances, as tempered by their co-variances:**

Expected Portfolio Risk = $$s_p = \sqrt{X_1^2 s_1^2 + X_2^2 s_2^2 + 2 X_1 X_2 r_{12} s_1 s_2}$$

  - s_1 and s_2 are the standard deviations of the annual costs of technologies *1* and *2*
  - $?_{12}$ is their correlation coefficient

- **The correlation coefficient is a measure of diversity. Lower correlation among portfolio cost components increases diversity, which reduces portfolio risk**

- **Adding a fixed-cost technology to a risky generating mix, even if it costs *more* than other alternatives, has the remarkable effect of *lowering* expected portfolio cost at any level of risk**
  - A pure fixed-cost technology, has $s_i = 0$. This lowers portfolio risk since two terms in the above Equation reduce to zero

UK Correlation Coefficients for Fuel Outlays

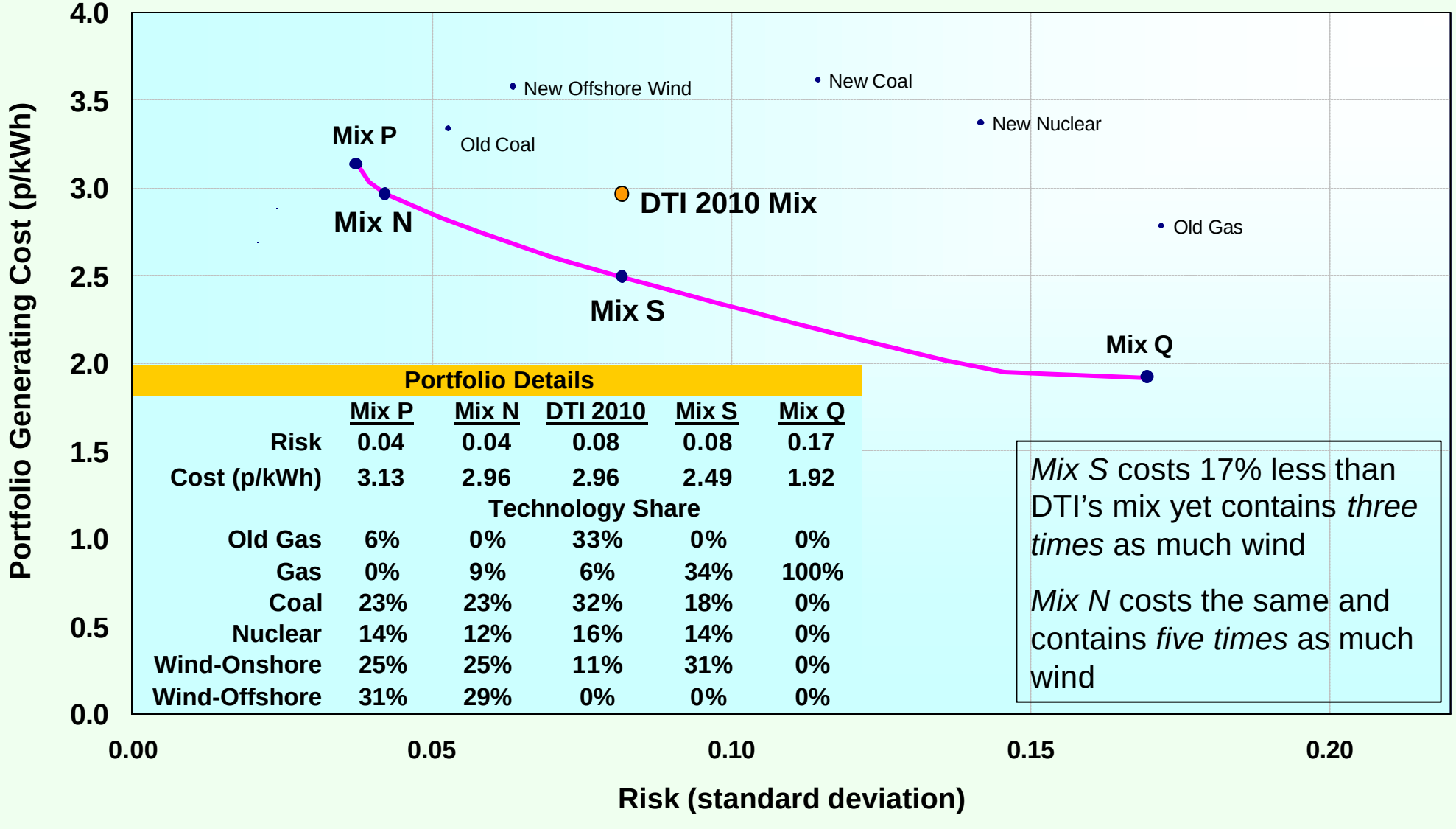
UK Historic Fuel Correlation Factors			
	Gas	Coal	Nuclear
Gas	1.000	0.195	0.251
Coal	0.195	1.000	-0.312
Nuclear	0.251	-0.312	1.000

Portfolio Optimization: Interpreting the Results

- **Charts Show Generating Portfolio Cost and Risk**
- ***Efficient Frontier*** **(pink line) is the location of all optimal mixes**
- **Mixes above the *EF* are inefficient: expected cost *and* risk can both be improved**
- **Along the EF, cost reductions attained only at higher risk**
- **Infinite solutions exist-- we locate the following *typical* mixes:**

- *Mix P:* Lowest-risk/highest-cost feasible optimal mix; usually most diverse
- *Mix N*: Equal-cost mix: *Minimum-risk* mix at DTI cost level
- *Mix S:* Equal-risk mix: *Minimum-cost* mix at DTI risk level
- *Mix Q*: Lowest-cost/highest-risk feasible optimal mix; usually least diverse

2010 Portfolio Optimization
DTI Technology Costs



Portfolio Details

	Mix P	Mix N	DTI 2010	Mix S	Mix Q
Risk	0.04	0.04	0.08	0.08	0.17
Cost (p/kWh)	3.13	2.96	2.96	2.49	1.92
Technology Share					
Old Gas	6%	0%	33%	0%	0%
Gas	0%	9%	6%	34%	100%
Coal	23%	23%	32%	18%	0%
Nuclear	14%	12%	16%	14%	0%
Wind-Onshore	25%	25%	11%	31%	0%
Wind-Offshore	31%	29%	0%	0%	0%

Mix S costs 17% less than DTI's mix yet contains *three times* as much wind

Mix N costs the same and contains *five times* as much wind

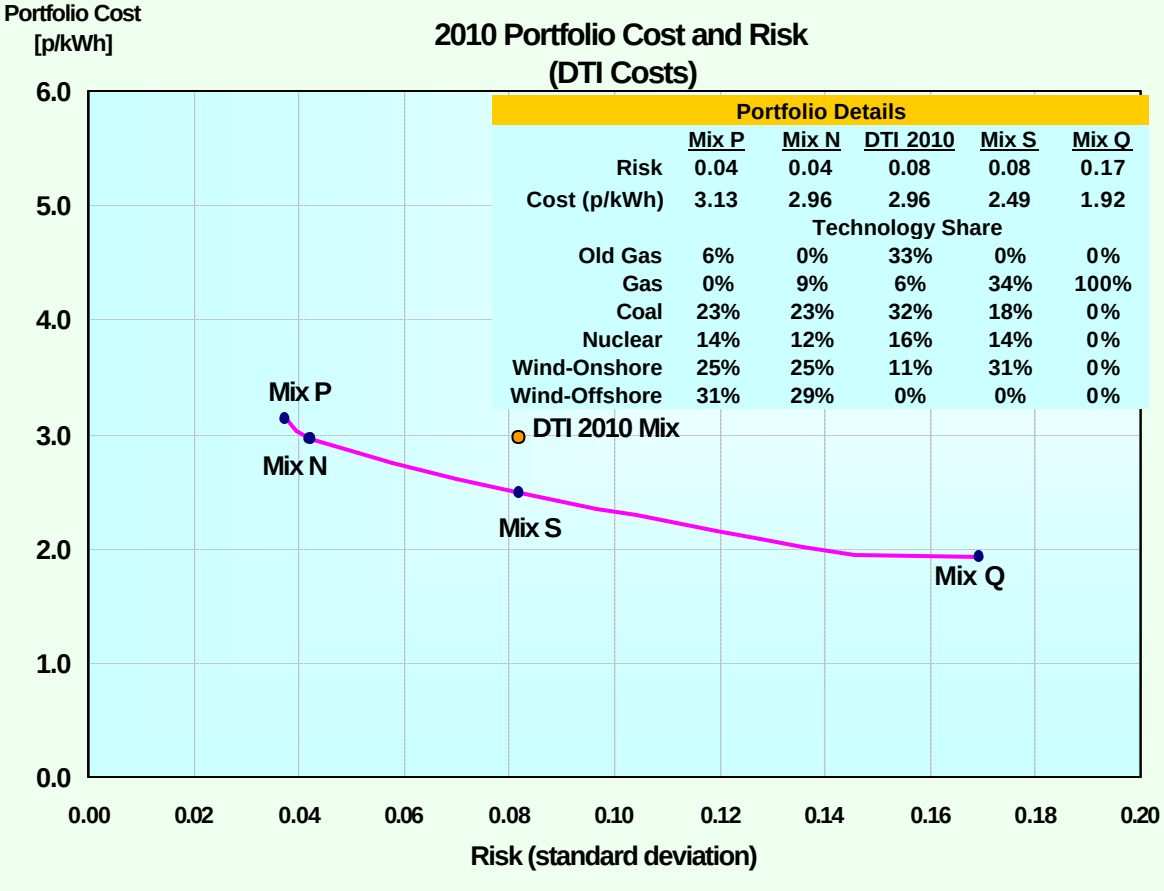
Analysis: 2010 Optimization - DTI Costs

- **DTI's target 2010 mix**
  - Generating Cost: 3 p/kWh
  - Wind Share: 11%
- **Portfolio optimization reveals superior alternatives, e.g.:**

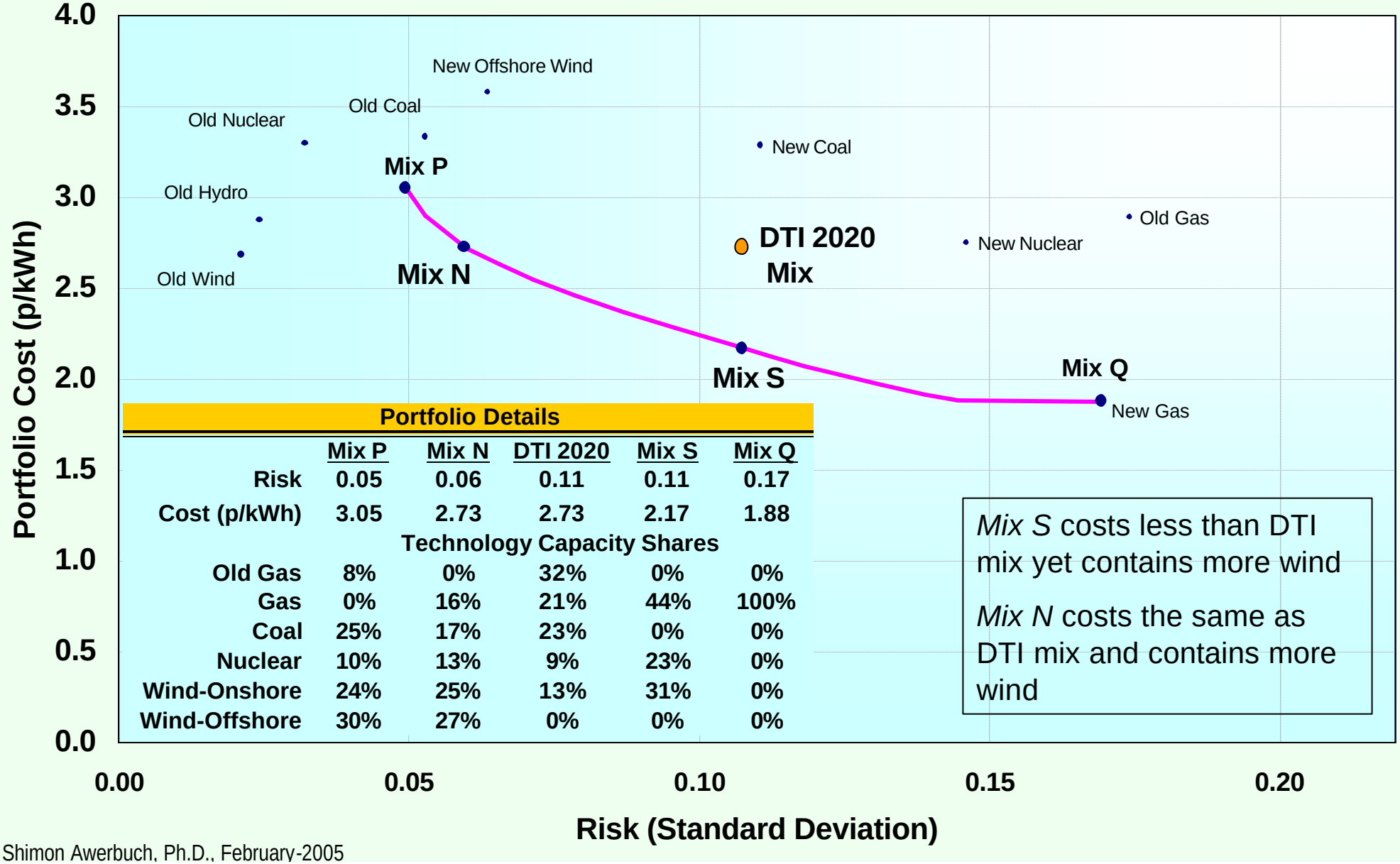
1. **Mix *N*:**
   - Generating cost: 3 p/kWh
   - Wind share = 54%

2. **Mix *S*:**
   - Costs: 2.5 p/kWh
   - Plus -- Wind share: 31%

3. **Infinite other solutions exist**



2020 Portfolio Optimization
DTI Technology Costs



Portfolio Details

	Mix P	Mix N	DTI 2020	Mix S	Mix Q
Risk	0.05	0.06	0.11	0.11	0.17
Cost (p/kWh)	3.05	2.73	2.73	2.17	1.88
Technology Capacity Shares					
Old Gas	8%	0%	32%	0%	0%
Gas	0%	16%	21%	44%	100%
Coal	25%	17%	23%	0%	0%
Nuclear	10%	13%	9%	23%	0%
Wind-Onshore	24%	25%	13%	31%	0%
Wind-Offshore	30%	27%	0%	0%	0%

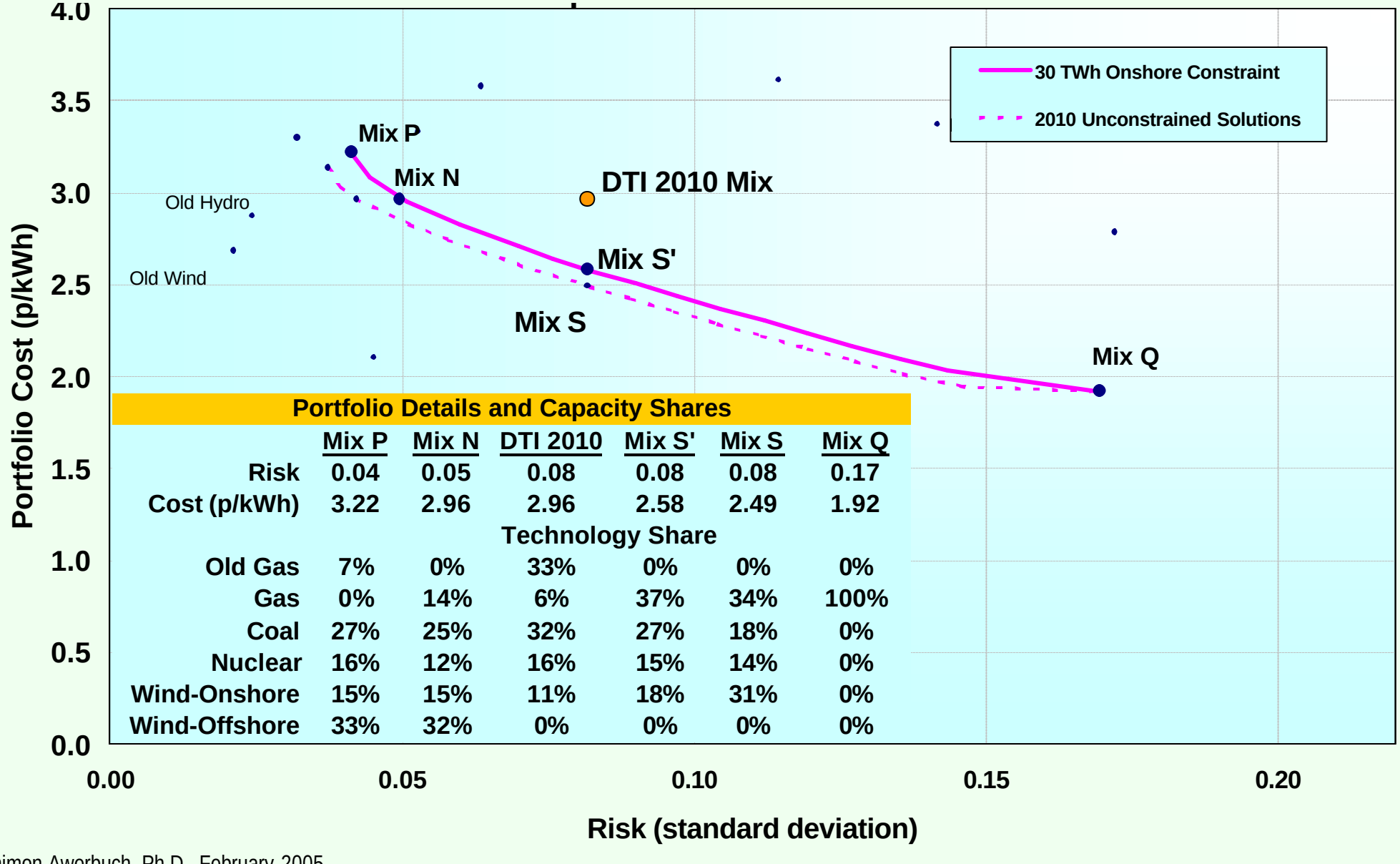
Mix S costs less than DTI mix yet contains more wind

Mix N costs the same as DTI mix and contains more wind

Planning and Other Constraints:

The Cost of Failing to Meet Full 2010 Wind Potential Under DTI Wind-Costs

Cost of Not Meeting 2010 Wind Potential: Optimal Mixes with On-shore Constrained to 30 TWH



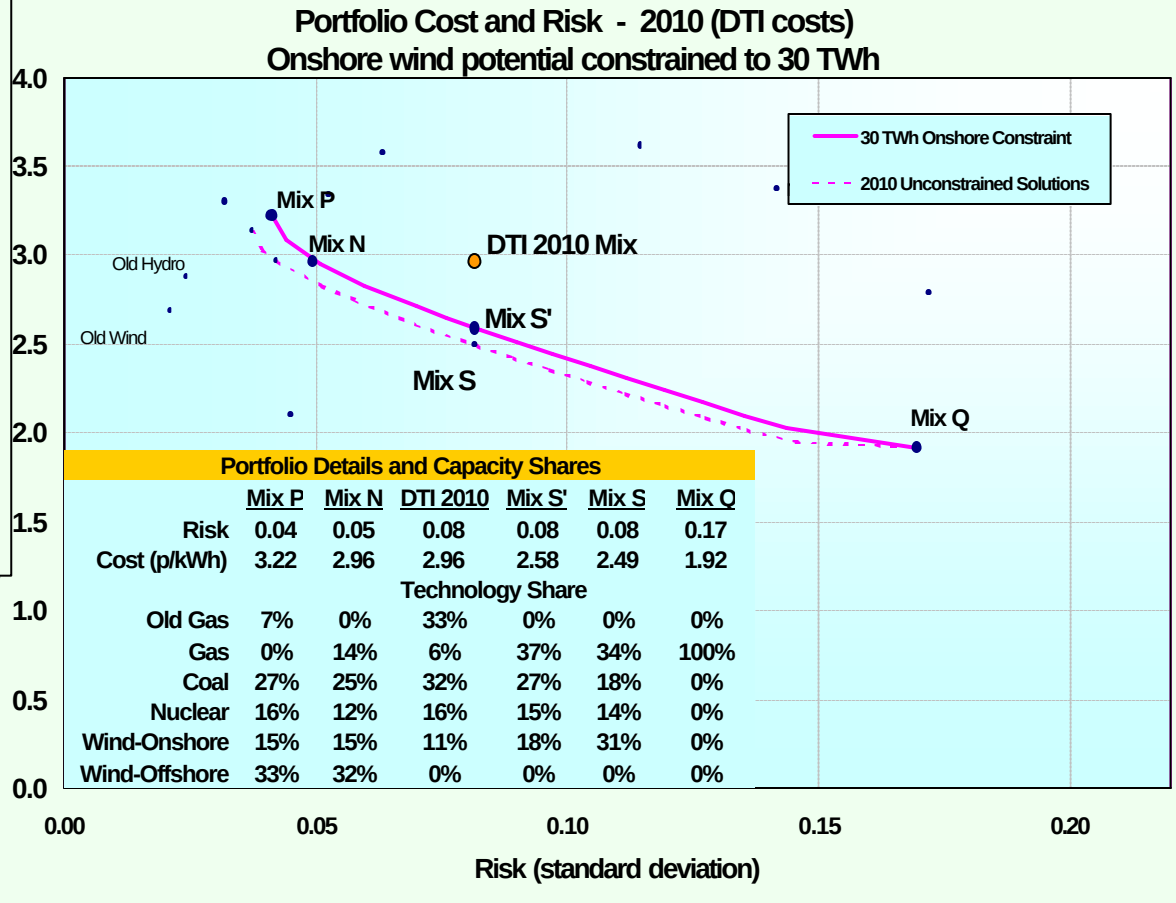
Portfolio Details and Capacity Shares

	Mix P	Mix N	DTI 2010	Mix S'	Mix S	Mix Q
Risk	0.04	0.05	0.08	0.08	0.08	0.17
Cost (p/kWh)	3.22	2.96	2.96	2.58	2.49	1.92
Technology Share						
Old Gas	7%	0%	33%	0%	0%	0%
Gas	0%	14%	6%	37%	34%	100%
Coal	27%	25%	32%	27%	18%	0%
Nuclear	16%	12%	16%	15%	14%	0%
Wind-Onshore	15%	15%	11%	18%	31%	0%
Wind-Offshore	33%	32%	0%	0%	0%	0%

Cost of Not Meeting Full 2010 Wind Potential

Planning and other constraints increase cost of 2010 optimal mix

Unconstrained Cost (Mix S)	2.49 p/kWh
Constrained Cost (Mix S')	2.58 p/kWh
Constraint Cost	0.09 p/kWh
Total energy demand	408 TWH
Total Constraint Cost	**£ 372 Million**

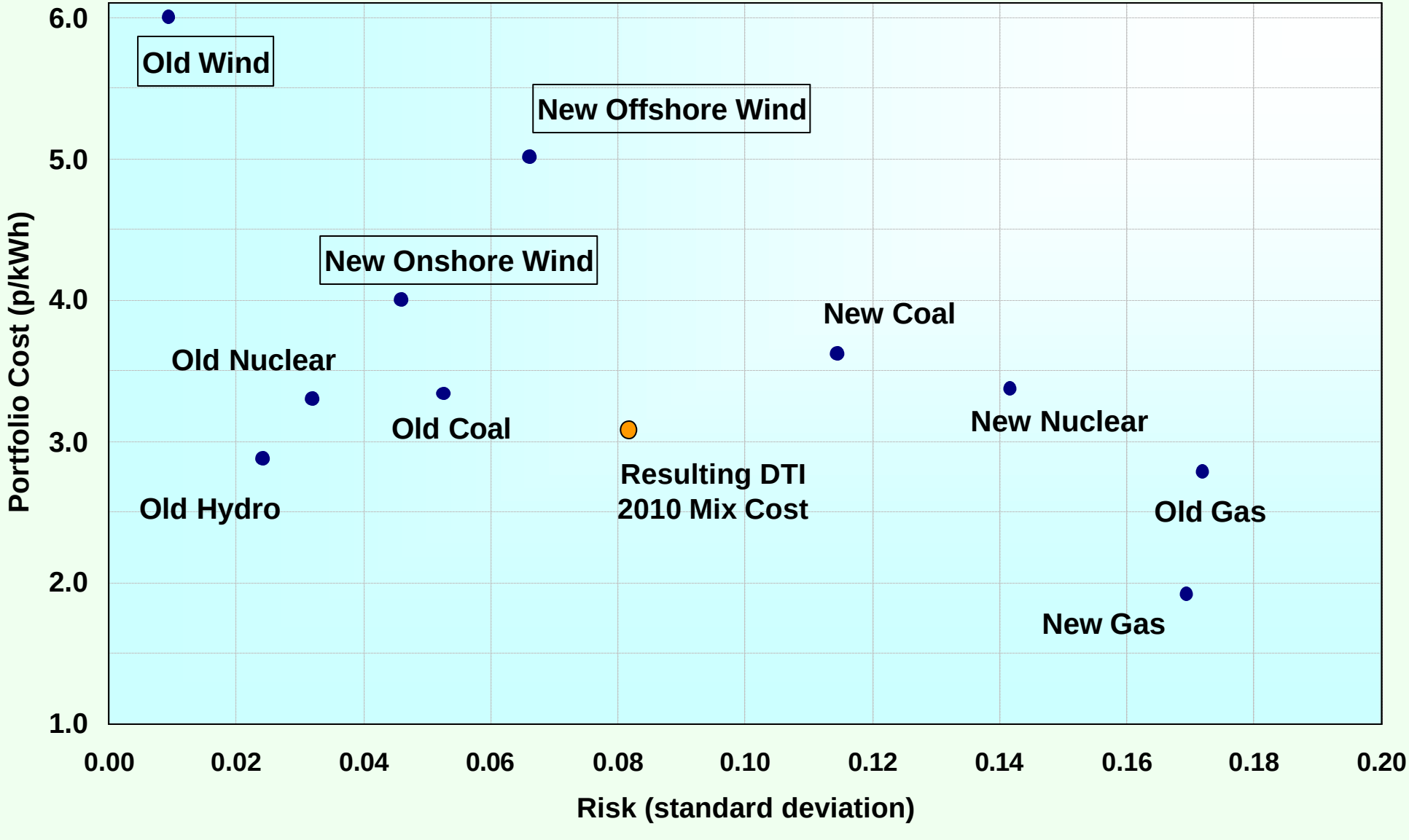


Portfolio Details and Capacity Shares

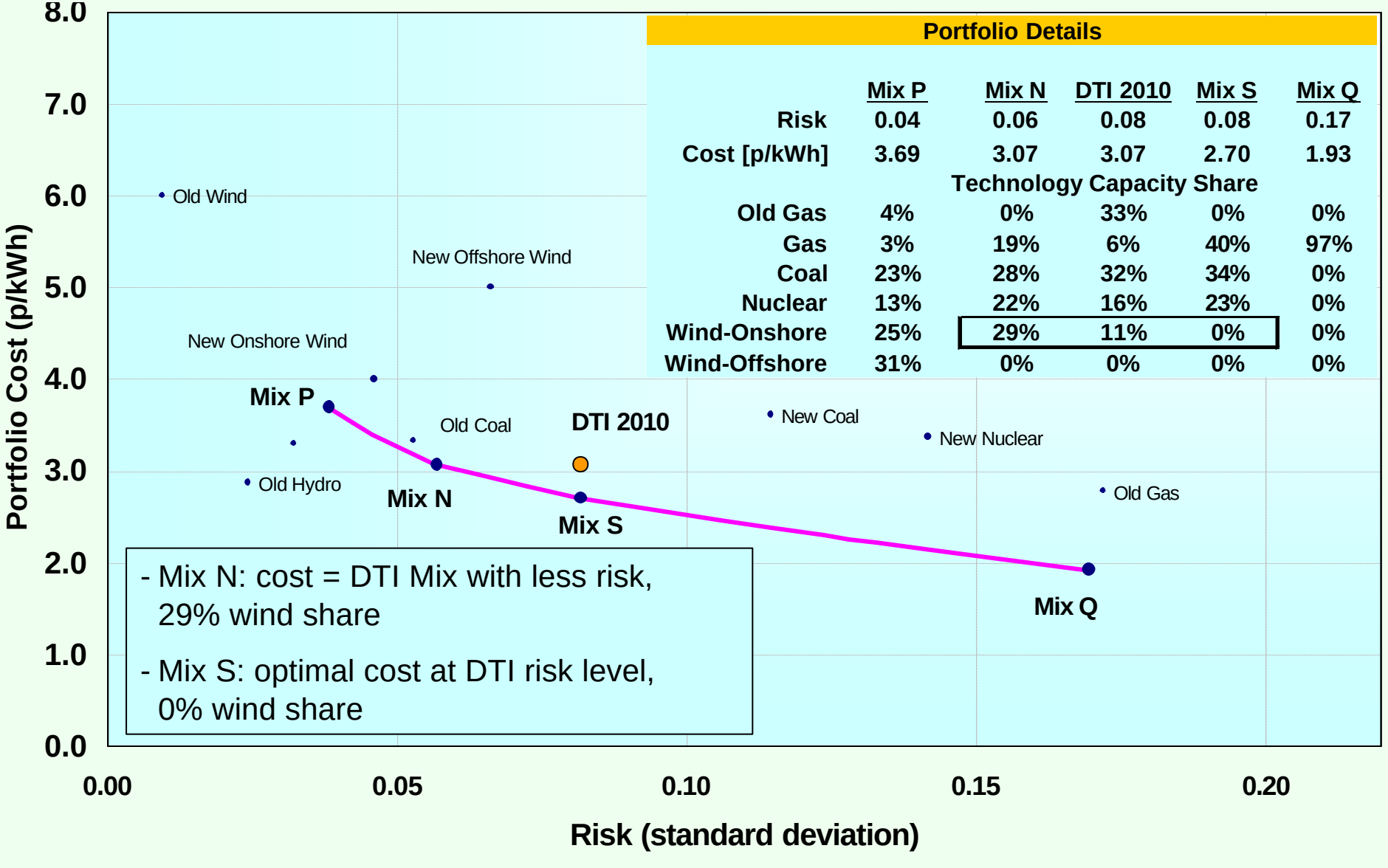
	Mix P	Mix N	DTI 2010	Mix S'	Mix S	Mix Q
Risk	0.04	0.05	0.08	0.08	0.08	0.17
Cost (p/kWh)	3.22	2.96	2.96	2.58	2.49	1.92
Technology Share						
Old Gas	7%	0%	33%	0%	0%	0%
Gas	0%	14%	6%	37%	34%	100%
Coal	27%	25%	32%	27%	18%	0%
Nuclear	16%	12%	16%	15%	14%	0%
Wind-Onshore	15%	15%	11%	18%	31%	0%
Wind-Offshore	33%	32%	0%	0%	0%	0%

Portfolio Optimization Using Less Optimistic Wind Costs

Technology Cost and Risk:
2010 Alternate Wind Cost Assumptions



2010 Portfolio Optimization
- Alternate Wind Costs -



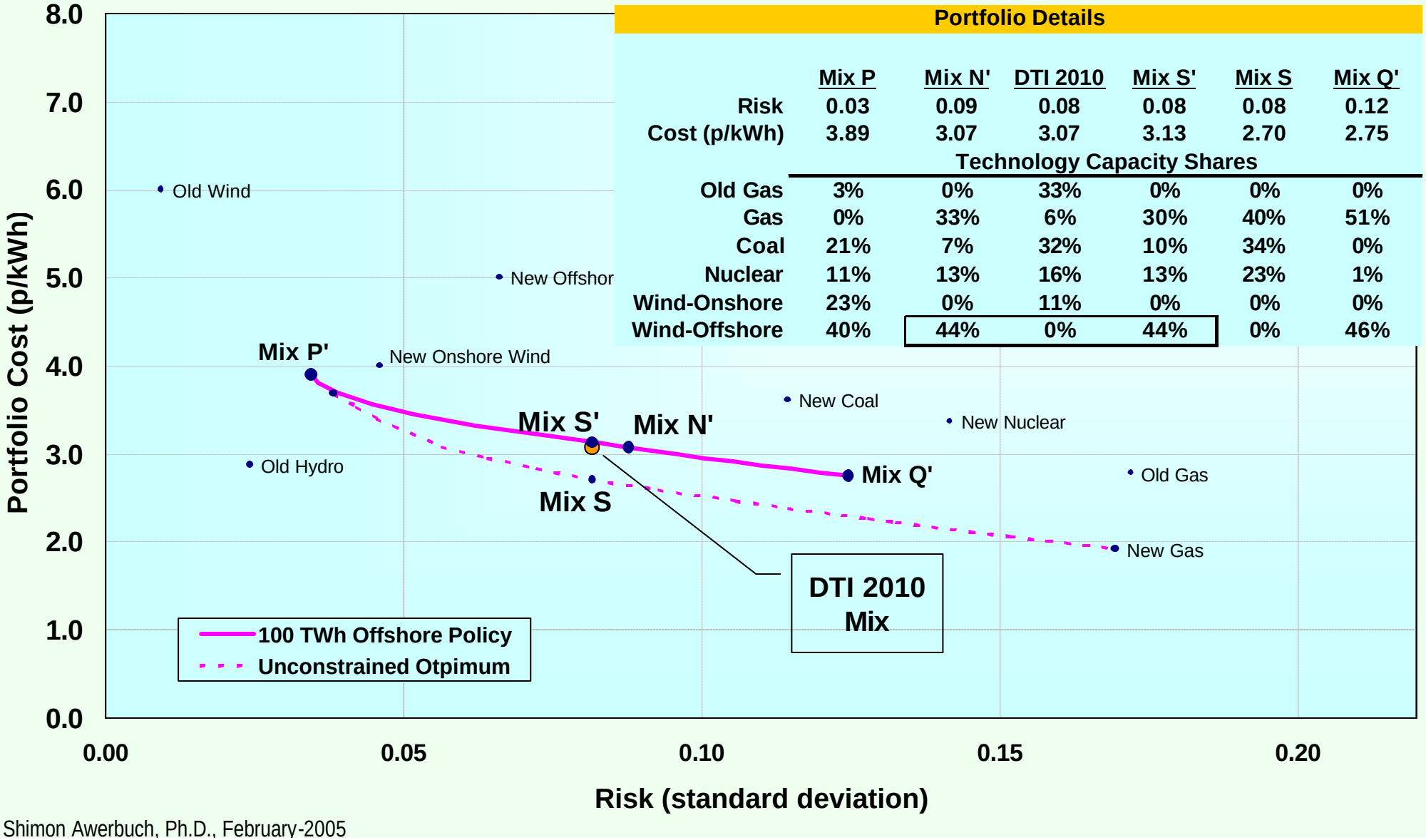
Additional Analysis of Alternate Wind Cost Scenario:

The Effect Of Accelerated Off-shore Wind Deployment

Motivation for This Analysis

- **The minimum cost mix (*Mix S*) for the Alternate Wind Cost Scenario contains no wind**
- **But there exist infinite other mixes at this risk level that do contain wind**
- **We explore the cost-risk of these possibilities by forcing the mix to include 100 TWH offshore wind. This is an arbitrary constraint, and is higher than the DTI maximum potential**
- **The optimization locates the efficient frontier (minimum cost points) that contain at least 100 TWH off-shore wind**

The Effect Of Accelerated Wind Deployment Policy - Alternate Wind Costs 2010

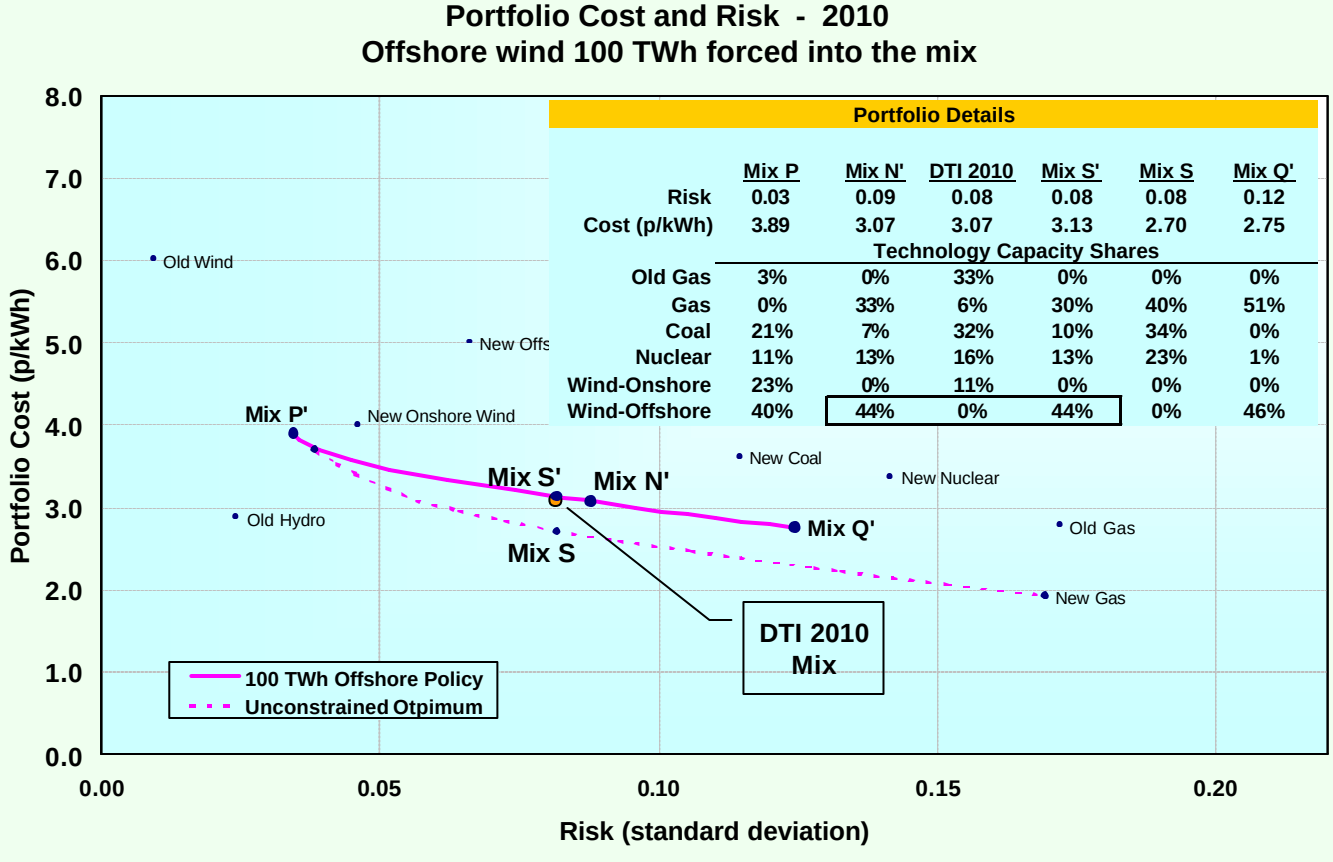


Portfolio Details

	Mix P	Mix N'	DTI 2010	Mix S'	Mix S	Mix Q'
Risk	0.03	0.09	0.08	0.08	0.08	0.12
Cost (p/kWh)	3.89	3.07	3.07	3.13	2.70	2.75
Technology Capacity Shares						
Old Gas	3%	0%	33%	0%	0%	0%
Gas	0%	33%	6%	30%	40%	51%
Coal	21%	7%	32%	10%	34%	0%
Nuclear	11%	13%	16%	13%	23%	1%
Wind-Onshore	23%	0%	11%	0%	0%	0%
Wind-Offshore	40%	44%	0%	44%	0%	46%

Analysis: Accelerated Wind Deployment Policy - Alternate Wind Costs 2010

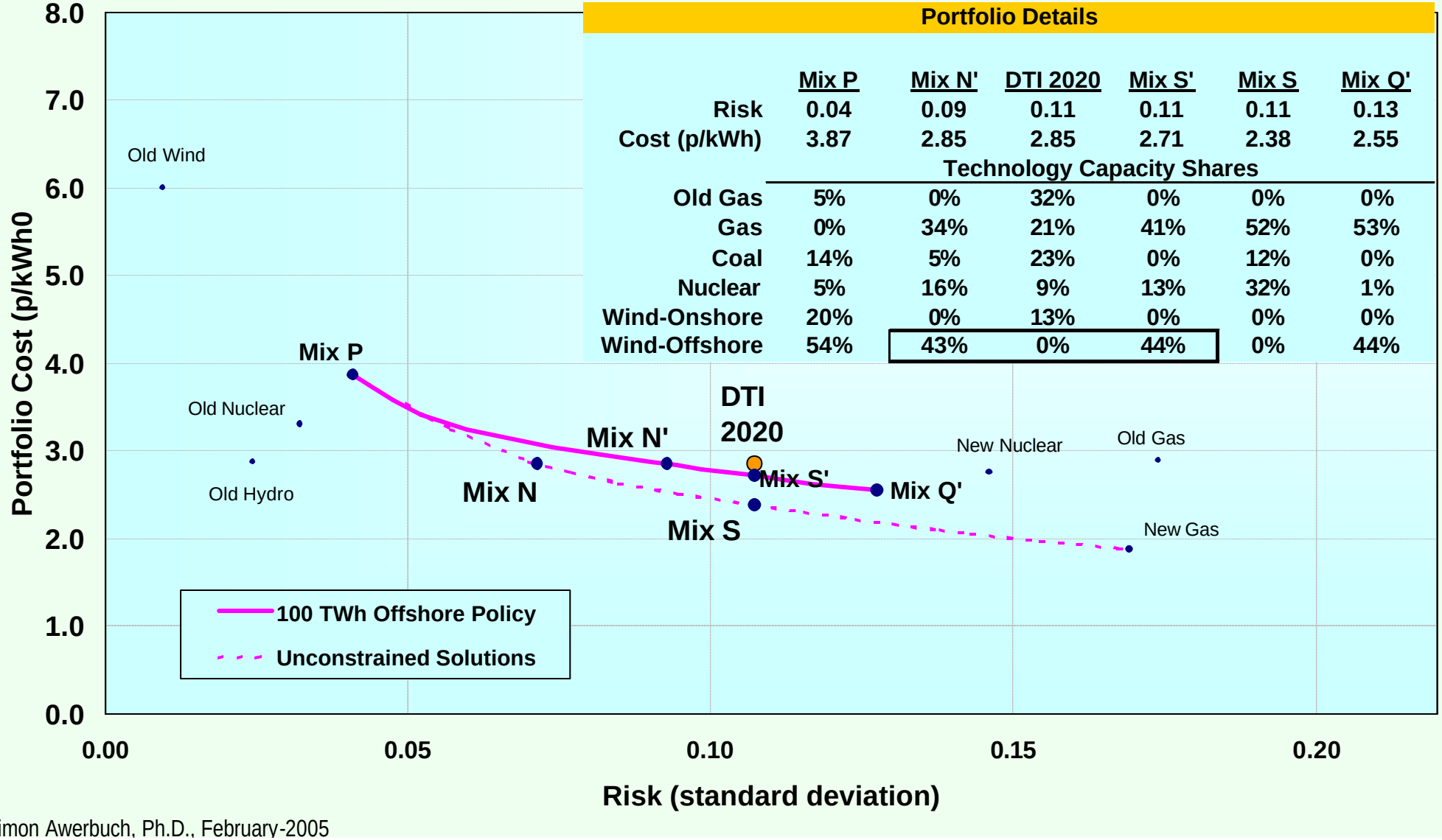
- **Cost of Accelerated Off-shore deployment under higher wind costs:**
  - **DTI Mix:**
    - 3.07p/kWh, 11% on-shore
  - **Unconstrained Mix S:**
    - 2.7 p/kWh, 0% wind
  - **Constrained Mix S':**
    - 3.13 p/kWh, 44% Off-shore



	Mix P	Mix N'	DTI 2010	Mix S'	Mix S	Mix Q'
Risk	0.03	0.09	0.08	0.08	0.08	0.12
Cost (p/kWh)	3.89	3.07	3.07	3.13	2.70	2.75
Old Gas	3%	0%	33%	0%	0%	0%
Gas	0%	33%	6%	30%	40%	51%
Coal	21%	7%	32%	10%	34%	0%
Nuclear	11%	13%	16%	13%	23%	1%
Wind-Onshore	23%	0%	11%	0%	0%	0%
Wind-Offshore	40%	44%	0%	44%	0%	46%

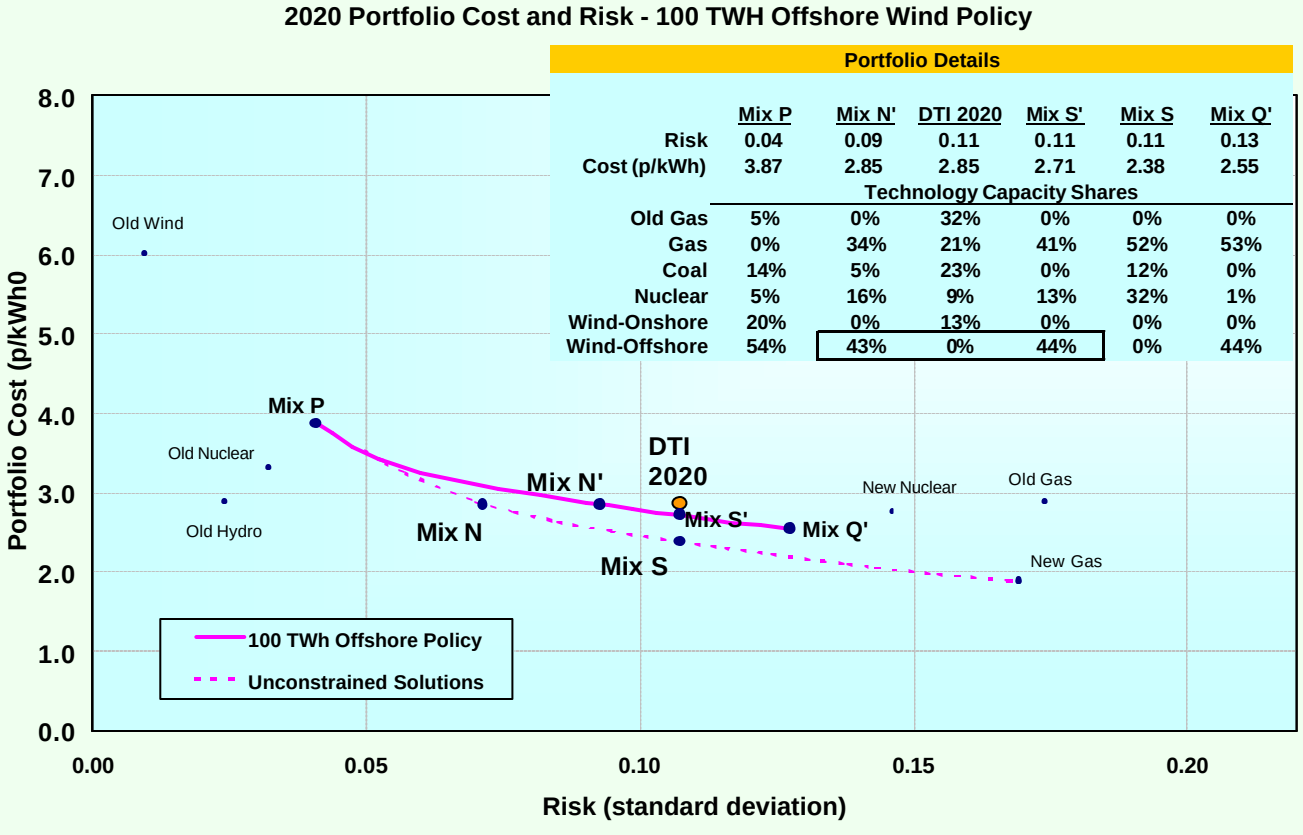
- **Generation cost impact of 100 TWH offshore deployment policy:**
  - **Relative to *DTI Mix:* 0.04 p/kWh**
  - **0.43 p/kWh higher than unconstrained optimum *Mix S***

The Effect Of Accelerated Wind Deployment Policy - Alternate Wind Costs - 2020



Analysis: Accelerated Wind Deployment Policy - Alternate Wind Costs 2020

- **Cost of Accelerated Off-shore deployment in 2020**
  - **DTI Mix:**
    - 2.85 p/kWh, 13% on-shore, 0% Off-shore
  - **Unconstrained Mix S:**
    - 2.38 p/kWh, 0% wind
  - **Constrained Mix S':**
    - 2.71 p/kWh, 44% Off-shore



- **2020 Cost impact of 100 TWH offshore deployment policy:**

  -- Relative to *DTI Mix:* -0.14 p/kWh

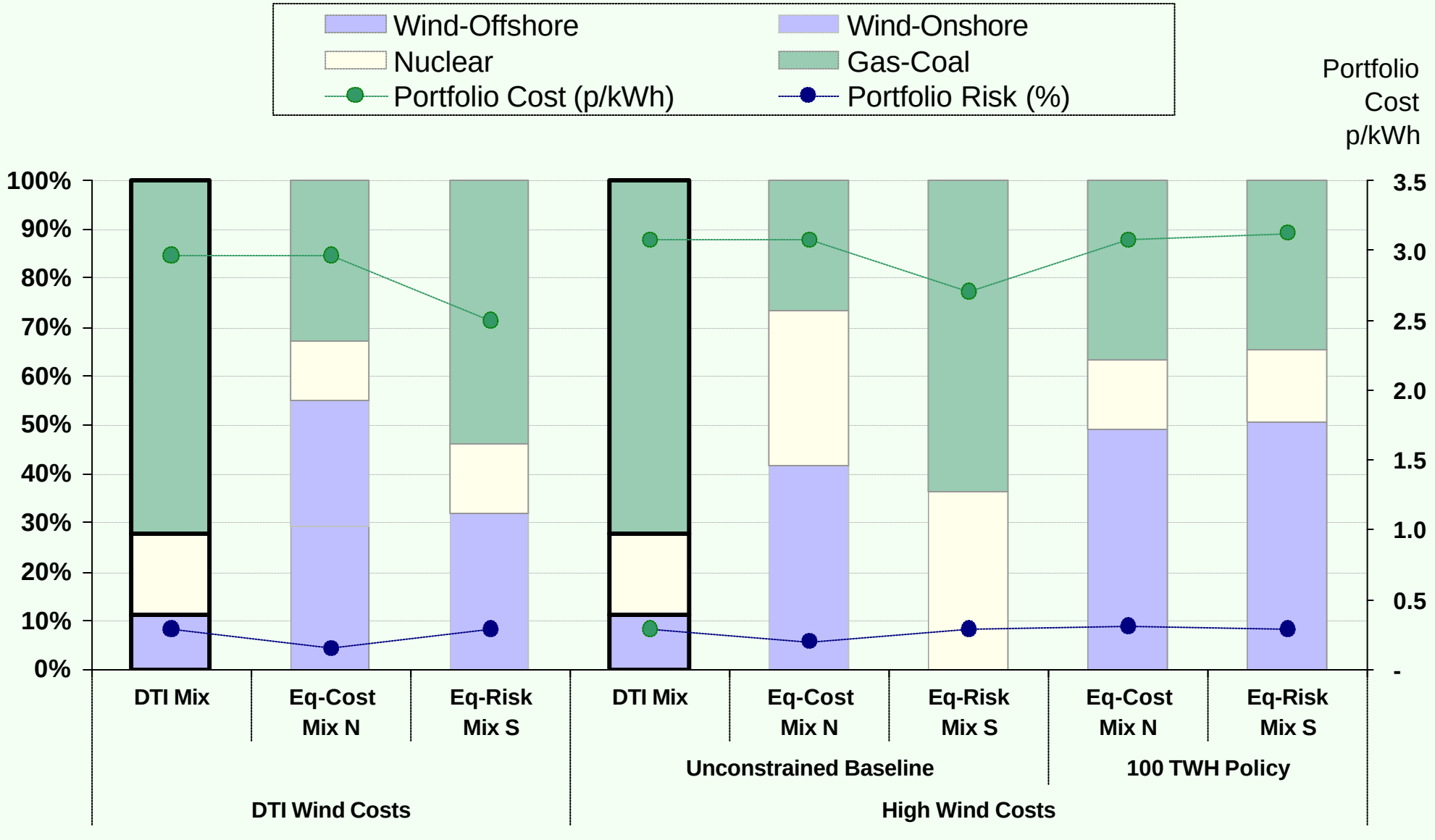
  -- Relative to unconstrained optimum *Mix S:* 0.33 p/kWh

Summary

2010 and 2020 Portfolio Technology Shares and Generating Cost for Different Scenarios

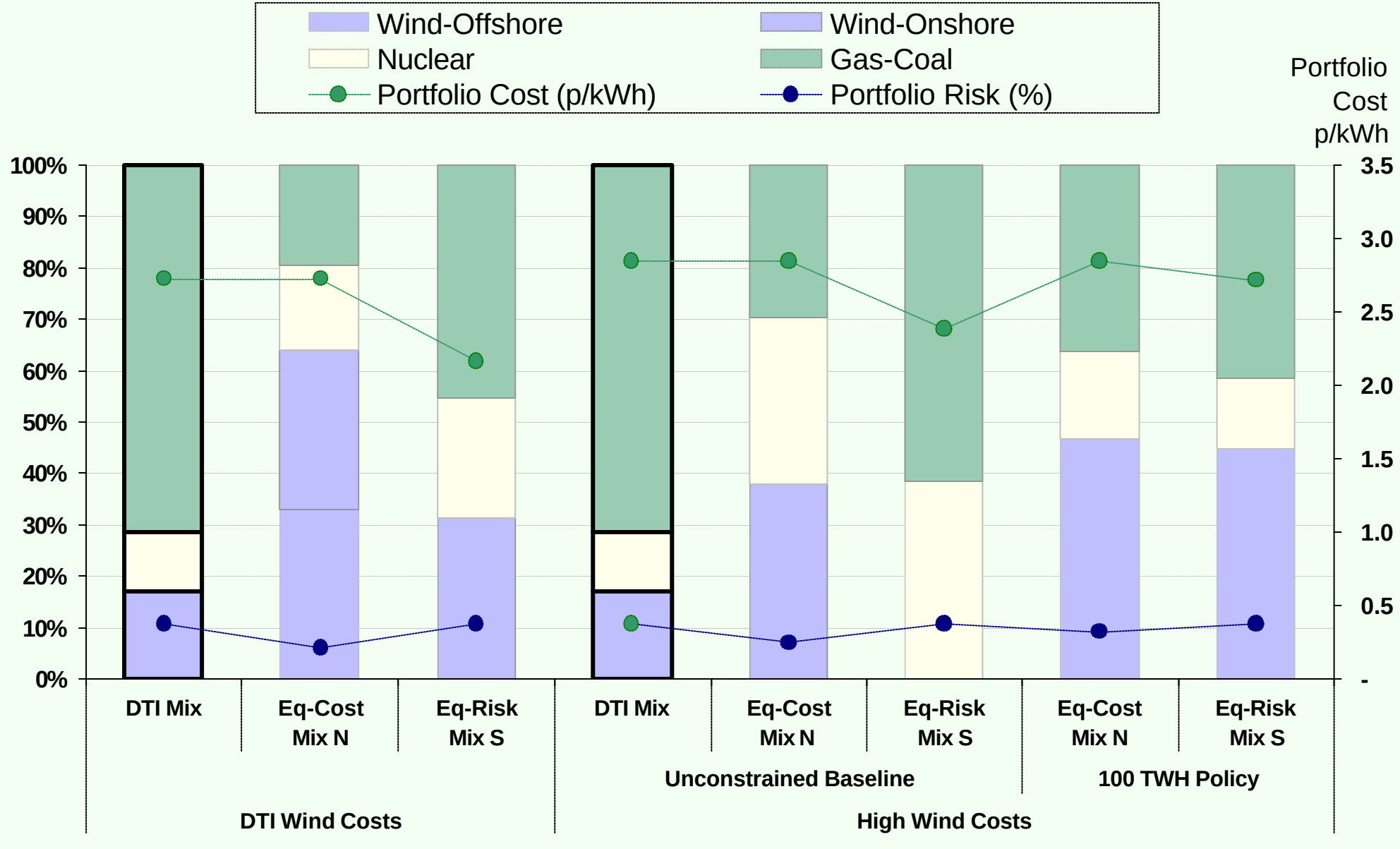
2010 Technology Capacity Share and Portfolio Cost-Risk

For Scenarios and Years Studied

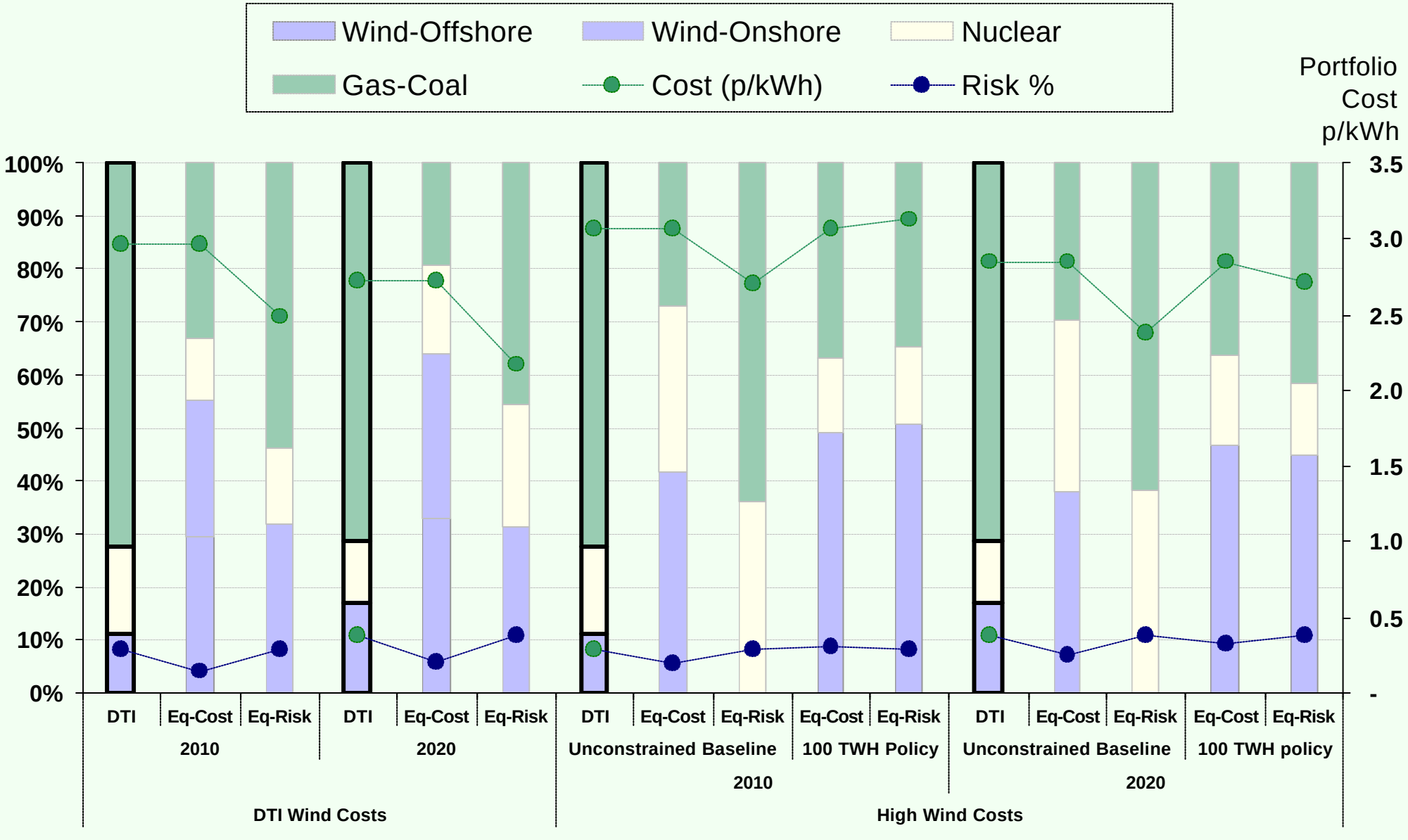


2020 Technology Capacity Shares and Portfolio Cost-Risk

For Scenarios and Years Studied



2010 and 2020 Technology Capacity Share and Portfolio Cost-Risk
For Scenarios and Years Studied



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Current and Projected UK MW-Capacity Shares

(Source: DTI)