

Economic analysis of carbon sequestration at stand level

Johanna Pohjola*

Lauri Valsta**

***Finnish Forest Research Institute**

****University of Helsinki, Department of Economics**

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Model characteristics

- Forest owner maximizes the discounted net returns over an infinite time horizon
- Stand level analysis; SMA optimization software
- MELA based growth models (individual-tree, distance-independent)
- Forest management options: rotation length, intensity and timing of thinnings

Joint production model

- Carbon sequestration in the model:

- joint production of timber and carbon sequestration:

maximize the total NPV from timber and carbon

$$\max \pi = \left[\sum_{t=0}^T \overset{\text{revenues related to harvests}}{(h_t - l_t - ec_t)(1+r)^{-t}} - w + \sum_{t=0}^T \overset{\text{related to growth}}{cr_t(1+r)^{-t}} \right] \frac{1}{1 - (1+r)^{-T}}$$

where

ht = stumpage return from harvest,

lt = logging cost,

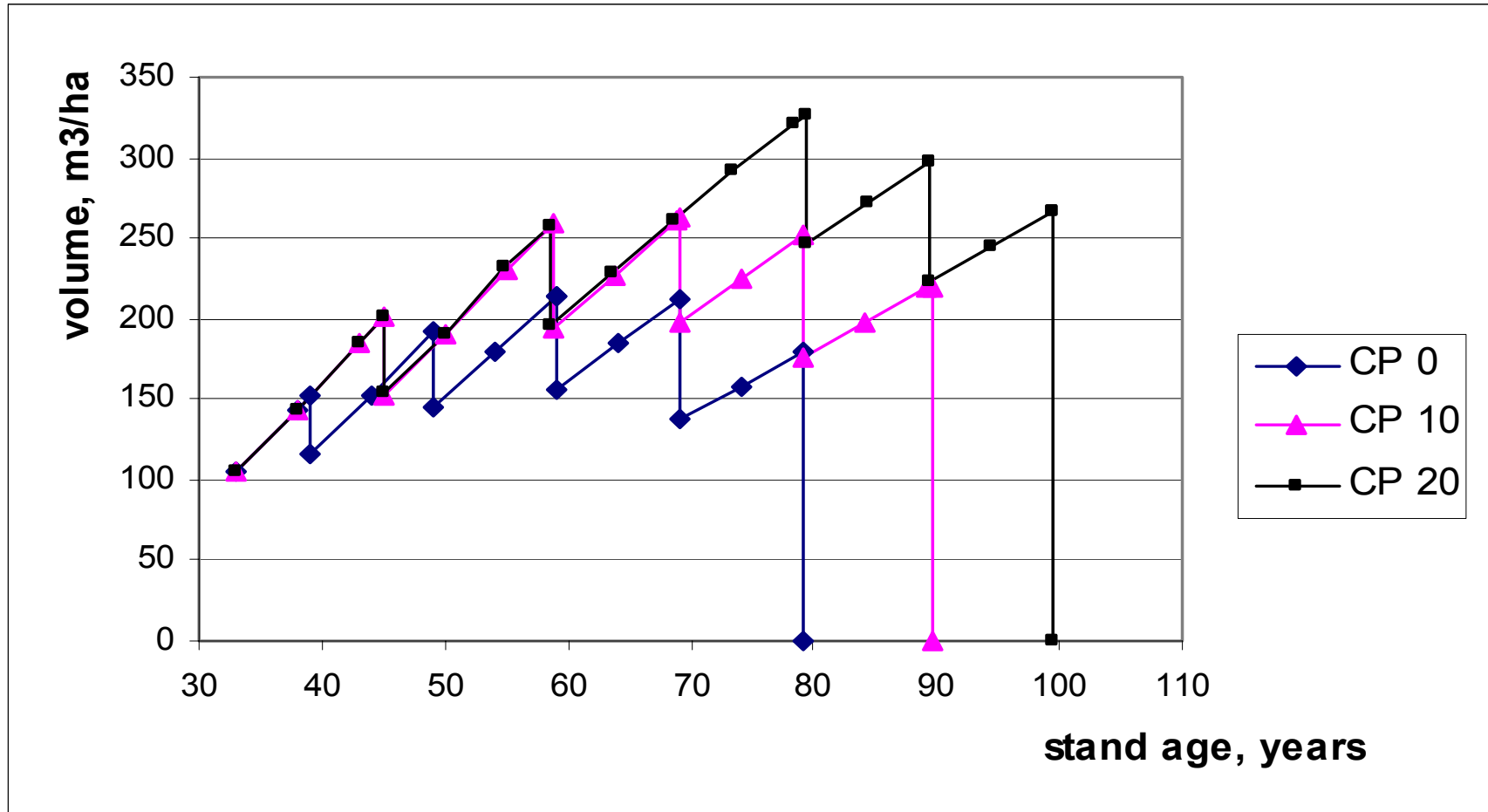
ect = emission cost related to harvest,

w = regeneration costs,

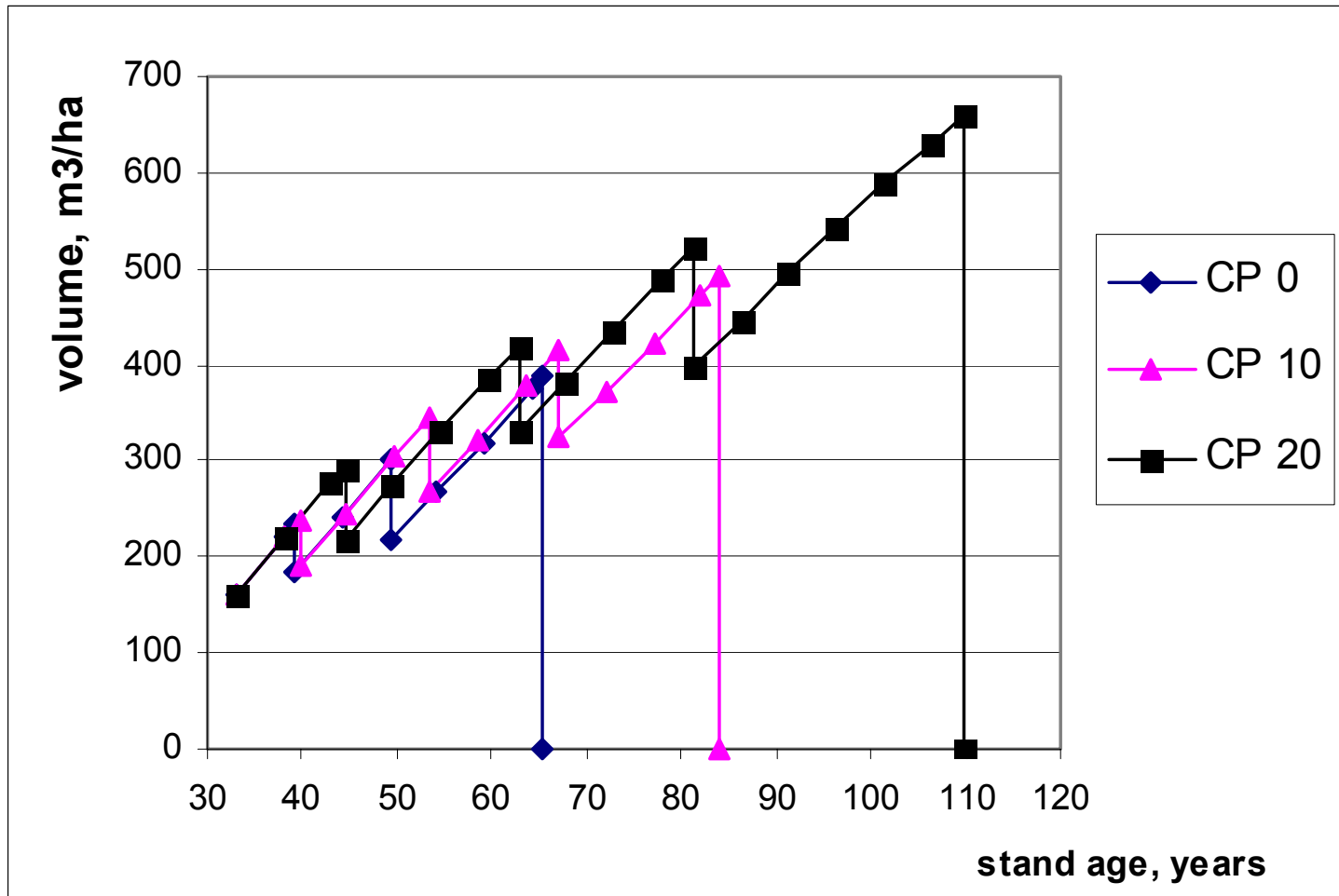
crt = carbon sequestration payment

all discounted at rate r for a rotation of T

Optimal silviculture for Scots pine with carbon prices of 0, 10 and 20 €/t CO₂



Optimal silviculture for Norway spruce with carbon prices of 0, 10 and 20 €/t CO₂



Scots pine

Carbon price, €/t CO ₂	0	10	20
Rotation length, yr	79 (62-96)	88 (71-104)	100 (86-121)
Average volume, m ³ /ha	116 (88-138)	148 (126-168)	178 (160-199)
Average carbon, t CO ₂ /ha	150 (114-180)	192 (163-204)	231 (207-257)

Norway spruce

Carbon price, €/t CO ₂	0	10	20
Rotation length, yr	64 (58-69)	81 (71-86)	110 (102-114)
Average volume, m ³ /ha	145 (123-160)	207 (167-231)	305 (259-336)
Average carbon, t CO ₂ /ha	219 (184-238)	309 (251-344)	455 (387-502)

Thinnings vs rotation length as a measure to increase C sequestration

- For Scots pine, delaying and lightening thinnings is found to be more cost-effective measure than increasing the rotation length.
- For most of the stands examined, 70-80 % of the increase in the average carbon storage during the rotation period was obtained by modifying thinnings, with a carbon price of 10 €/t CO₂.
- For Norway spruce, increasing the rotation length appears to be more cost-effective
- With thinnings it is possible to increase the carbon sequestration only to some extent, and the more carbon is sequestered per hectare, the higher share of sequestration has to be obtained by lengthening the rotation period.

- The forest owner could not however affect much the net income from carbon sequestration by changing the stand management.
- For Norway spruce stands in average, the joint income would increase from 1894 €/ha to 2980 €/ha even without any change in the silviculture, if carbon price were 10 €/t CO₂. As applying an optimal silviculture would increase the total NPV to 3140 €/ha, the additional benefit from modifying silviculture would be 160 €/ha.
- The results are similar for Scots pine stands.

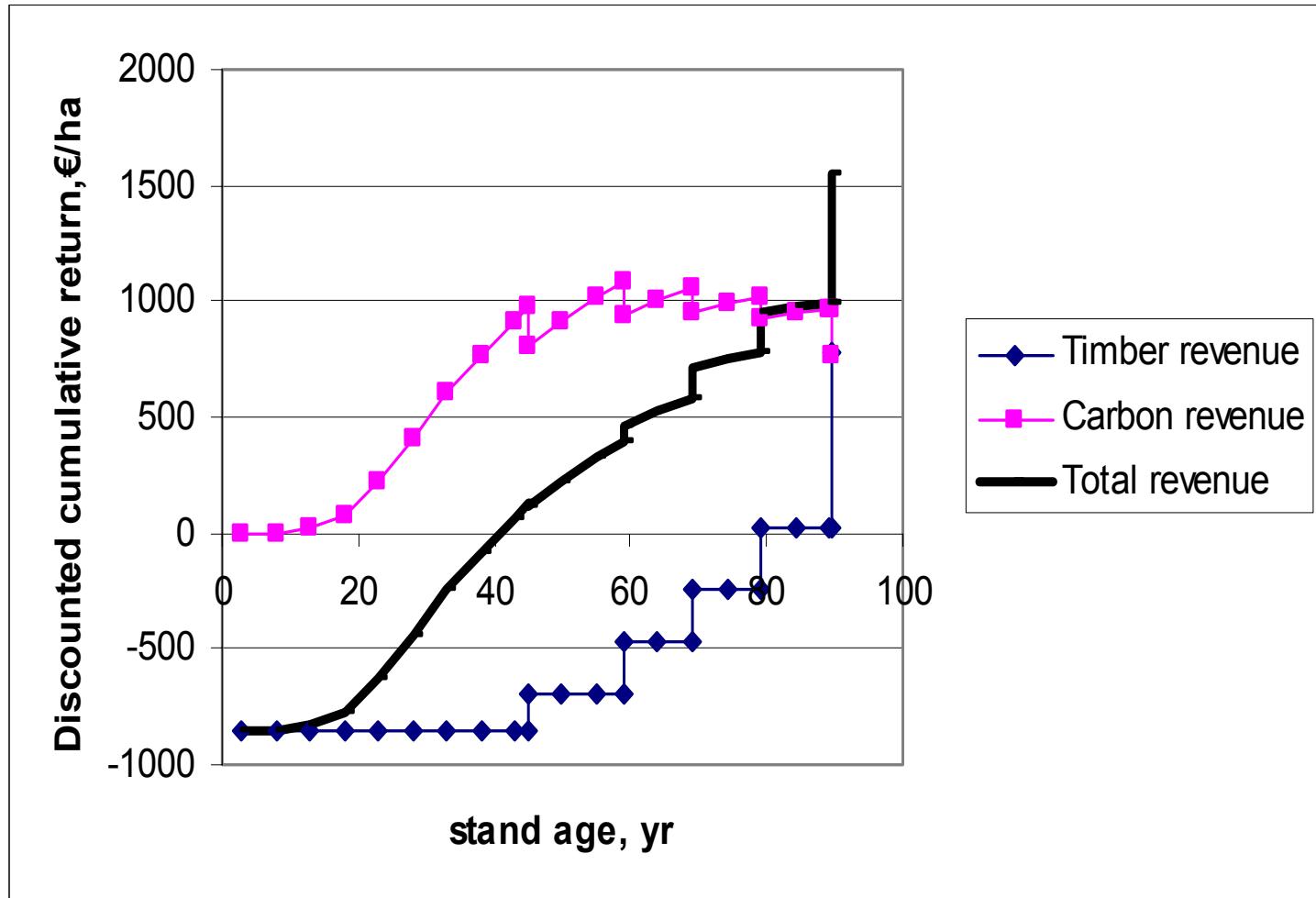
Timber yield, Scots pine

Carbon price, €/t CO ₂	0	10	20
Timber yield, m ³ /ha/y			
Sawlog	3.6	4.1	4.2
Pulpwood	1.9	1.7	1.5
Total*	5.6	5.8	5.8
Change relative to base case (no value for carbon), %			
Sawlog		12.5	17.3
Pulpwood		-8.6	-19.6
Total		5.2	4.7

Timber yield, Norway spruce

Carbon price, €/t CO ₂	0	10	20
Timber yield, m ³ /ha/y			
Sawlog	4.4	5.4	5.8
Pulpwood	3.6	3.1	3.0
Total*	8.1	8.7	8.8
Change relative to base case (no value for carbon), %			
Sawlog		23.2	30.6
Pulpwood		-12.9	-16.6
Total		6.7	8.6

Time paths of timber and carbon revenues



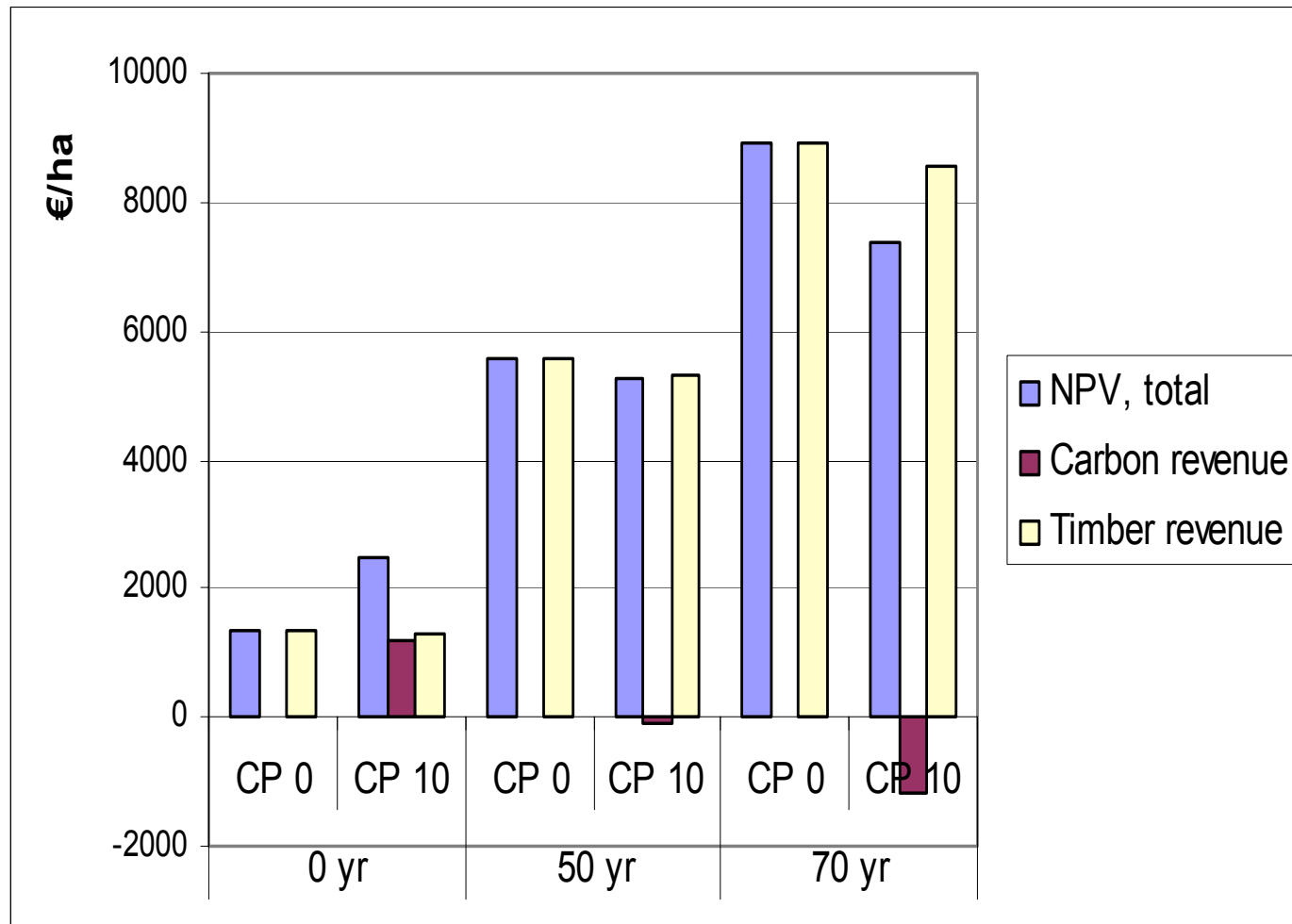
Discounted revenues, Scots pine)

	Carbon price, €/t CO ₂		
	0	10	20
NPV timber, €/ha	1156	1064	869
NPV carbon, €/ha		998	2246
NPV total, €/ha	1156	2061	3115
Change in NPV timber, %		-8.0	-24.6
Change in NPV total, %		78.3	169.5

Discounted revenues, Norway spruce

	Carbon price, €/t CO ₂		
	0	10	20
NPV timber, €/ha	1894	1701	1095
NPV carbon, €/ha		1439	3688
NPV total, €/ha	1894	3140	4783
Change in NPV timber, %		-10.2	-42.2
Change in NPV total, %		65.8	152.6

Revenues for three different ages (0, 50 and 70 yrs), with carbon prices of 0 and 10 €/t CO₂ Scots pine



Conclusions

- **Thinnings have an important role in increasing carbon sequestration**
- **Carbon subsidy/tax programme had a positive impact on the annual timber yield due to the considerable increase in the yield of sawlog**
- **The impacts are somewhat different for Scots pine and Norway spruce**