Estimating Carbon Supply Curves for Global Forests and Other Land Uses

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Abstract

This study develops cumulative carbon "supply curves" for global forests utilizing an dynamic timber supply model for sequestration of forest carbon. Because the period of concern is the next century, and particular time points within that century, the curves are not traditional Marshallian supply curves or steady-state supply curves. Rather, the focus is on cumulative carbon cost curves (quasi-supply curves) at various points in time over the next 100 years. The research estimates a number of long-term, cumulative, carbon quasi-supply curves under different price scenarios and for different time periods. The curves trace out the relationship between an intertemporal price path for carbon, as given by carbon shadow prices, and the cumulative carbon sequestered from the initiation of the shadow prices, set at 2000, to a selected future year (2010, 2050, 2100). The timber supply model demonstrates that cumulative carbon quasi-supply curves that can be generated through forestry significantly depend on initial carbon prices and expectations regarding the time profile of future carbon prices. Furthermore, long-run quasi-supply curves generated from a constant price will have somewhat different characteristics from quasi-supply curves generated with an expectation of rising carbon prices through time.

The "least-cost" curves vary the time periods under consideration and the time profile of carbon prices. The quasi-supply curves suggest that a policy of gradually increasing carbon prices will generate the least costly supply curves in the shorter periods of a decade or so. Over longer periods of time, however, such as 50 or 100 years, these advantages appear to dissipate.

Key Words: carbon supply curves, sequestration, timber, forests, model, global warming, prices, markets

JEL Classification Numbers: Q10, Q15, Q21, Q23, Q24

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Introduction

This study develops cumulative carbon "supply curves" for global forests utilizing a dynamic timber supply model for sequestration of forest carbon. Since the period of concern is the next century and particular time points within that century, the curves are not traditional Marshallian supply curves or steady-state supply curves. Rather, the focus is on cumulative carbon cost curves (quasi-supply curves) for various time points over the next 100 years. The curves trace out the relationship between an intertemporal price path for carbon, as given by carbon shadow prices, and the cumulative carbon sequestered by a point in time. The model demonstrates that long-run, cumulative, carbon quasi-supply curves that can be generated through forestry depend importantly on initial carbon prices and expectations as to the time profile of future carbon prices. The cost functions are generated for some future time, for example, 2010, 2050 or 2100. Long-run quasi-supply curves generated from a constant price will have somewhat different characteristics from quasi-supply curves generated with an expectation of rising carbon prices through time. Least-cost curves vary depending upon the time periods under consideration.

The General Approach

The general approach is to compare carbon captured in the forest and in forest products in the base case, where forest carbon has no price, with cases where carbon is a joint forest product, with timber, therefore having value and a price. The base case is not static, but dynamic in that it extends trends in deforestation and afforestation through the 21st century under the assumption that carbon has no price. This base case result is compared with several scenarios in which carbon becomes a joint product with timber and alternative shadow prices of carbon are

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postulated with various time paths and value levels. The amount of net carbon generated is the difference between that of the base case and that of the various scenarios.

Additional forest carbon can be generated by three means. First, more land can be put into timber. Second, existing forests can be grown for longer periods by extending the harvest rotation, sometimes indefinitely. Finally, additional management can be applied to increase the rate of forest growth, and consequently the amount of carbon sequestered in a stand at any given age. Providing a price for carbon provides incentives for increasing forests by each of these means. Using the projections of carbon price and outputs through time, under the various scenarios, long-term, cumulative, carbon cost functions are estimated at selected points in time over a period of one century.

The general approach takes the following steps. First, three scenarios with seven cases are selected. Each scenario represents a generic type of intertemporal price path, referred to as a family of price profiles, such as constant price, rising at some rate, stabilizing at some future time. Second, the profiles for cumulative carbon sequestration above the base case and through time are undertaken for seven alternative price scenarios (figure 1, pg. 12). Third, the relationship between carbon price and time is traced out (figure 2). Fourth, the relationship between price and cumulative carbon (above the base) is traced out (figure 3). Fifth, the relationship between price and cumulative carbon for three selected years, 2010, 2050, and 2100 is presented. Each of the three clusters of points represents a price-cumulative carbon relationship for a different year (figure 4). Sixth, the relationship between carbon price and cumulative carbon sequestered for a given year is traced out for each of the three scenarios for each of the three selected years. The connection of price-cumulative quantity points is called a cumulative carbon quasi-supply curve, since it is established only for a given family (figures 5, 6, and 7).

The Model

The basic approach uses a dynamic timber supply model (Sohngen, Mendelsohn, and Sedjo 1999) that provides time profiles for a number of important variables including forest biomass, timber harvests, and associated forest carbon. It should be noted that the timber supply model has been refined and updated from an earlier version to include more accurate empirical parameters (Sohngen and Sedjo 1999).

Our approach assumes an idealized situation in which optimizing behavior is obtained in the forestry sector. The base case considers the time path of these variables in a hypothetical setting where timber is produced in an economically optimal amount through time and no distortions or policies exist. The economic incentives for timber production induce economic activities that create more forest stock through planting, management, and silviculture to increase forest growth on existing sites. Base-case forest biomass volumes are estimated for the year 2000 and projected to year 2100 (table 1, pg. 22). Under this approach, forest biomass decreases gradually through the 21st century as tropical deforestation exceeds the net reforestation that is occurring in mid-latitudes in response to anticipated increases to the economic demand for timber and other forces.

Additionally, the model provides for the establishment of newly planted forests in response to incentives provided by the market. In the base case, no incentives are provided for carbon production and forest carbon changes are simply the inadvertent outgrowth of forestry activities driven by market considerations and other forces that result in deforestation and afforestation. In the base case, forests may replace agriculture when the returns to forestry activities exceed those to agriculture on a given piece of land, and vice versa. The relevant cost functions in the model include a cost of planting function, a land-value function, a forest-management cost function, and a harvesting cost function in primary forests. Thus, the costs in the cumulative carbon cost functions developed using the model incorporate costs from these various activities that expand or contract global forested areas.

The base-case timber model has two distinct stocks of carbon. The first carbon stock is that contained in the forest ecosystem, including biomass and soils. The second carbon stock is in the long-lived wood products that are created from the harvested wood. This second stock has additions in the form of new wood products and deletions as products have completed their useful life and eventually burn or decompose. The base case is dynamic through time and assumes a carbon shadow of zero.

We hypothesize various different annual carbon shadow prices and optimize the forest sector's response to those prices. Although the carbon shadow prices are denominated as in-perpetuity present values (discounted at 5%), the model assumes annualized (rental) payments are made for carbon sequestration that exceeds that of the base case.[1] An optimizing hypothesis is that shadow prices trace the marginal social damage costs. One variant of this approach examined in this paper uses shadow prices that trace the marginal damage costs as estimated by

[1] The use of a rental approach allows sequestered carbon to be directly compared with and related to carbon emission reductions achieved elsewhere in the economy, e.g., through the energy sector, thereby integrating carbon decisions across sectors (see Sohngen, Mendelsohn, and Sedjo 2001).

Nordhaus and Boyer (2000).[2]

Furthermore, our approach assumes that society has the traditional option of abating carbon emission through the energy sector as well as through forestry. Consequently, the carbon sequestration prices facing the forest sector are assumed to be identical to those facing the energy sector. This analysis provides an estimate of the carbon sequestration potential of the forest sector in a context where carbon sequestration is being undertaken in concert with actions in the energy sector. However, to the extent that concerted actions would affect the costs associated with the damage function, the shadow prices reflecting those damages would need to be adjusted downward. Under our model, shadow prices are not adjusted.

Three Scenarios

Three sets of scenarios are developed to examine the effects of providing financial incentives for carbon sequestration using forestry. For each scenario assumptions are made regarding the time paths of the carbon shadow price. In each scenario a somewhat different time path for shadow-prices is assumed and rental payments are made for carbon sequestration consistent with the annualized, discounted, present value. If shadow prices represent the damage function, then mitigation will occur up to the point where the costs of mitigation equal the value of the damages. Timber also continues to receive its market economic return in each scenario.

Scenario 1: Carbon price is set at a given level for 2000 and increases 2.5% annually until 2150. Following Nordhaus and Boyer, case one begins at a carbon shadow price of $5 per year and increases at an annual rate of 2.5%. Case two begins at a carbon price of $20 per year and also increases at a 2.5% rate through 2150.

Scenario 2: Carbon price set at a given level in 2000 and held constant indefinitely. Case one sets the carbon price at $50 per ton. Case two sets the carbon price at $100 per ton.

Scenario 3: Carbon price level given for 2000 and increases 2.5% annually until it stabilizes in 2060. Three cases begin with the initial price of carbon at $5, $20, and $50 per ton.

A cumulative, carbon-sequestration quasi-supply curve—that is the cumulative carbon sequestered over and above that of the base case—can be estimated for each scenario that

[2] The damage cost path assumed by Norhaus and Boyer could be modified by sufficient carbon sequestration activities. In this paper our shadow prices assume that path is unaffected.

provides an estimate of the cumulative carbon sequestered up to a given year, such as 2050, for the various assumed carbon price paths of the various cases.

The Scenario Results

In the first scenario, the assumed shadow-price path is broadly consistent with Nordhaus and Boyer (2000).[3] The two cases in scenario one are assumed to begin at discounted present value levels of $5 and $20 in year 2000. They increase until 2150 at an annual rate of 2.5%.

Tables 1 and 2 give the price/cumulative carbon quantity relationships through time and by region for the two cases in scenario 1. Cumulative carbon is the quantity of carbon stored in forests relative to the base zero shadow-price path. For example, in 2050 the cumulative carbon stored is 11.2 gigatons (Gts) above what it would have been in the base case. By 2100, stored carbon is 47.72 Gts above the base level for 2100.

The second scenario involves a fixed shadow-price proposal. The fixed prices involve a discounted present value of $50 and $100, which remains constant through time. Again the model assumes that mitigating activities in each period are undertaken up to the point where the marginal costs associated with the activities equal the fixed shadow price. Tables 3 and 4 present the projections of price and cumulative carbon quantity for this scenario through time and by region.

The third scenario involves the same assumptions as above, where the initial shadow price levels are set at $5, $20, and $50 respectively and price growth rates are 2.5% per annum. However, price growth ceases in 2060 and the price remains at this level indefinitely. This has been called the “silver bullet” scenario in that it predicates a situation where carbon prices stabilize at some future time due to the introduction of some type of backstop technology. This scenario could occur, for example, if an alternative energy source was found to substitute for carbon-generating fossil fuels at some fixed cost above that of fossil fuels. Tables 5, 6, and 7 present projections of the price/cumulative quantity relationships (quasi-supply curves) for the three cases of scenario 3 through time and by region.

The time profiles for total cumulative carbon gain through time for each of the seven

[3] Nordhaus and Boyer focus on estimates of damage due to increases in atmospheric carbon. In this study we simply characterize their estimates of damage as the shadow prices assumed for the analysis.

cases is presented in figure 1. These profiles show increasing total carbon for all seven cases through time. Not surprisingly, the time profile for the higher price cases of the scenarios tends to collect a larger amount of carbon at any point in time. This point is examined further below.

Figure 2 provides the intertemporal price profiles for each of the seven cases through the 100-year period.

Figure 3 provides the price-cumulative quantity relationship for each of the seven cases through the 21st century. These curves are drawn from the price and cumulative carbon quantity points in tables 1 through 7. For example, the scenario showing a $5 initial price rising 2.5% annually to 2150 traces out a path from its initial intersection with the price axis at $5 per ton rising to a price of $47.72 at the end of the century. Each point on this relationship is associated with a different year moving left to right from 2000 to 2100. As the price progresses through time, the cumulative carbon captured in the system increases.

The five rising-price cases all have a positive relationship between price and quantity. Note that those stabilizing after 2060 do not reach either the price or cumulative carbon levels of those that continue to experience price rises through the entire century. For the two fixed-price cases, the price-quantity relationship is simply a point relating the fixed price to the total cumulative carbon sequestered in the century. A time path could be represented by a horizontal path from the price line to the cumulative carbon stock at the end of the century. Note that the fixed price cases are not entirely comparable to the other five cases.

Scenarios 1 and 3 have similar paths through the lower prices and quantities for the parallel cases beginning with $5 and $20 per ton. However, these begin to diverge toward the higher-price quantity end, because scenario 1 anticipates even higher prices whereas scenario 3 does not.

Figure 4 presents a series of price-cumulative, carbon quantity points drawn from the seven cases for years 2010, 2050, and 2100. The different periods are noted by different shapes at the point estimates. Since some of the points in 2010 approximately coincide, only five points appear for this year. The points in any year, for example, 2010, represent the series of price-cumulative carbon combinations that could be achieved in that year under the different price path scenarios. Note that although the price and cumulative quantity levels are that of a given year they are associated with different long-term price paths.

Forest Carbon Quasi-Supply Curves

In Figures 5, 6, and 7, we attempt to present something resembling long-term supply curves for three selected future years, 2010, 2050, and 2100. Each quasi supply curve is generated by points on shadow price paths from a family of similar price paths.

For example, the curve associated with scenario 1—rising prices in figures 5, 6, and 7—represents a family of intertemporal price paths, specifically those rising at 2.5% annually and stabilizing after 2150. The constant price curve chooses points from the two constant price scenarios ($50 and $100). Consequently, there is a price-cumulative, carbon-quantity relationship for the constant price family for a given year, in this case 2010, 2050, and 2100. Similarly, a price-cumulative, carbon-quantity relationship can be given for a third family of intertemporal prices: those rising at 2.5% annually and stabilizing after 2060.

For any given year the relationship between price and cumulative carbon captured can be given as a single point for any intertemporal price path. The series of points for a given year covering an entire family of similar intertemporal price paths—constant, rising to 2060, or rising to 2150—constitutes what we call a cumulative, carbon quasi-supply curve. As such it shows the relationship between the cumulative carbon sequestered and the price for a family of similar types of price paths.[4]

These curves are not quite what is known in economics as long-run supply curves, since they are not steady-state curves (hence the term quasi-supply curves is used). However, they do represent the relationship between the amount of carbon cumulatively sequestered between 2000 and the selected year (e.g., 2050) and the carbon price in the selected year drawn from a family of similar intertemporal price paths, as given in each of the three scenarios.

Figure 5 presents the three cumulative, carbon-sequestration quasi-supply curves for 2010 based on the three price scenarios. The model gives cumulative, mitigated carbon volumes of about 2 Gts and 7 Gts at prices of $6 and $21 for the two cases in of scenario 1. The highest (most costly) quasi-supply curve for 2010 is that based on scenario 2 with the constant price of carbon. Scenario 2 gives total carbon mitigation by 2010 of about 6 Gts at a price of $50 per ton

[4] One could calculate a price-carbon quantity curve for a specific time (such as a year) as the difference between the cumulative carbon supply curve in year t, and that of year t-1.

and 17 Gts at a price of $100 per ton. Finally, for the three cases of scenario 3, the cumulative volumes are 2, 7, and 14 Gts at carbon prices of $6, $21, and $67. Obviously, additional points can be generated to more completely trace out the curves. Since the first two points of scenario 1 and 3 are very similar, this section of the two supply curves overlaps. The highest point, 14 Gts at $67, represents the scenario where the price stabilizes in 2060.

Figure 6 presents the three quasi-supply curves for 2050. Scenario 1 provides points on a supply curve at about $21 for 10 Gts and $70 for 41 Gts. Under scenario 2, two points on the constant price curve give total carbon mitigation by 2050 of about 25 Gts at a price of $50 per ton and 60 Gts at a price of $100 per ton. A third quasi-supply curve is based on scenario 3, the rising future price scenario, which stabilizes in 2060. This supply curve gives mitigated carbon volumes of about 10, 41, and 80 Gts, at carbon prices of about $21, $70, and $180. Again, the first two points are fairly similar for either of the rising price cases (scenarios 1 and 3). Note that the highest (most costly) quasi-supply curve is no longer that based on a constant price of carbon, but is now associated with rising carbon prices, especially for the higher carbon volumes. However, at prices below about $80 per ton, the supply curves have quite similar price/quantity relationships.

Figure 7 presents the three quasi-supply curves for 2100. The quasi-supply curve based on scenario 1—the rising future price scenarios where price rises continue until the year 2150—gives mitigated carbon volumes of about 45 Gts and 140 Gts at carbon prices of about $70 and $250. The two points on the constant price curve, scenario 2, now give the total carbon mitigation by 2100 of about 40 Gts at a price of $50 per ton and 90 Gts at a price of $100 per ton. A third, now-more-distinct supply curve emerges for the third scenario, that is, the case of rising carbon prices stabilizing in 2060. Here the volumes are 18, 65, and 135 Gts, at prices of $17, $70, and $175. Note that the highest (most costly) quasi-supply curve is now based on the scenarios where prices continue to rise until 2150. Again, it will be noted that the time profiles for scenarios 1 and 3, price stabilization in 2060 and 2150, are very similar for starting conditions in the early years. However, they tend to increasingly diverge in the later years as the different future price gradually assumes a greater importance in carbon sequestration decisions.

The Application of this Approach to Other Land Uses

The key to applying this type of approach to other land uses is in the treatment of the outputs as joint products with each of the joint products having a separate value. In agriculture, for example, the critical component to this approach would be to view the output of agriculture as the joint product of a crop (or crops) and incremental additions to soil carbon. Under such an approach, the decision as to whether a suitable piece of land would go into forestry or agriculture would depend on the discounted present value of the land for forest/carbon verses that of crop/carbon land. In such an approach the land returns would equate at the margins that consider the land values generated by the joint products.

Discussion

Our research estimated long-term cumulative carbon quasi-supply curves under three different sets of price scenarios. The quasi-supply curves suggest that a policy of gradually increasing carbon prices will generate the least costly supply curves, particularly in shorter periods of a decade or so. Intuitively, this is probably due to the choice of low-cost projects in the near term and a deferring of some higher-cost carbon projects to the future when prices are expected to be higher. However, over longer periods of time, such as 50 or 100 years, these advantages seem to dissipate as the higher-cost projects are undertaken in the face of higher carbon prices.

This shift in choice of low-cost approaches as the targets switch from the relatively short-term to the longer-term is of some policy relevance. Fixation on short-term targets without consideration of the longer-term objectives can lead to the choice of less-cost-effective sequestration approaches. This problem could apply to the Kyoto Protocol approach where the targets for 2008-2012 are given independently of any clear knowledge of longer-term targets.

Figure 8 compares global carbon stored in forests over the 21st century for the base case, namely a zero carbon price, and for that of scenarios 1 and 3. The total carbon sequestered over the century in the high-price scenario (Scenario 1, case 2) is estimated at a very substantial 138 Gts, or an average of 1.38 Gts per year for the century. Table 8 compares the initial carbon storage estimated for this study with that of Dixon et al. (1999). Our model indicates that in the business-as-usual scenario (a zero carbon price), the forest carbon stock is projected to fall by about 29 Gts over the 100-year period (table 9) or roughly a decline of 3.5% in total forest carbon. However, that decline can be reversed through policies that treat the forest output as a joint product, timber and carbon, and provide payments for carbon. Under scenario 1, case 1, with a carbon price of $61 in 2100, the estimated total carbon sequestered over the 21st century would be 11.78 Gts higher than in the baseline (figure 8). If the price were $244, as with case 2, carbon sequestered in 2100 would be 138.42 Gts above the baseline. This increase above the baseline is equal to 3 to 9 %of the anticipated total increase in atmospheric carbon, about 1600

Gts, should the business-as-usual case prevail. Although not overwhelming in terms of the total amount of carbon, sequestration of forest carbon can clearly make a significant contribution to overall atmospheric carbon mitigation over the next century.

The effect in the shorter term can be even more profound. The shorter term approach could be relevant if there was a consensus that biological sequestration would be an appropriate response in the next couple of decades, but less so over the longer period. This shift in perspective may occur because of political considerations, such as the Bush administration's decision not to seriously try to reduce energy related carbon dioxide emissions in the next several years, or a strategic decision to rely on biological sequestration until more carbon-efficient energy systems are developed (e.g., fuel cells). At current levels of carbon build-up, by 2010 there will be about 34 Gts of additional carbon in the atmospheric, as gradual deforestation continues. Figure 5 indicates that, with the assumed positive carbon prices, forests could sequester an additional 2 to 16 Gts of carbon over that period. In other words, forest carbon sequestration could offset from 5 to almost 50% of the anticipated business-as-usual atmospheric carbon build-up.

The breakdown of forest carbon storage by global regions also provides some interesting insights. Figure 9 presents a distribution by region for 2010 and 2100 for scenario 1, case 1, which shows carbon prices rising until 2150, for the $20 case. Note that Figure 10 provides estimates of timber prices and the total stock of forest carbon for the 21st century. By far, most of the carbon sequestration occurs in South America, Africa, and the Asia-Pacific region. The primary reason for this is a reduction in the rate of deforestation as forest carbon values become large enough to discourage forest conversion to agriculture. In 2010, 60% of storage occurs in these regions, with another 26% in the region of the former Soviet Union. North America accounts for 8%, and the European Union, only 2%. Perhaps this small amount of carbon storage accounts for the EU's resistance to using carbon sinks under the Kyoto Protocol. By 2100, the shares of sequestered carbon of South America, Africa, and the Asia-Pacific region remain roughly the same. However, the carbon share of North America has doubled while that of the former Soviet Union has fallen to roughly one-third of its 2010 share. Over that century, the share of carbon stored in the European Union increases by 200%, albeit from a small base.

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Figure 1. Time Profiles for Carbon Sequestration under the Alternative Cases

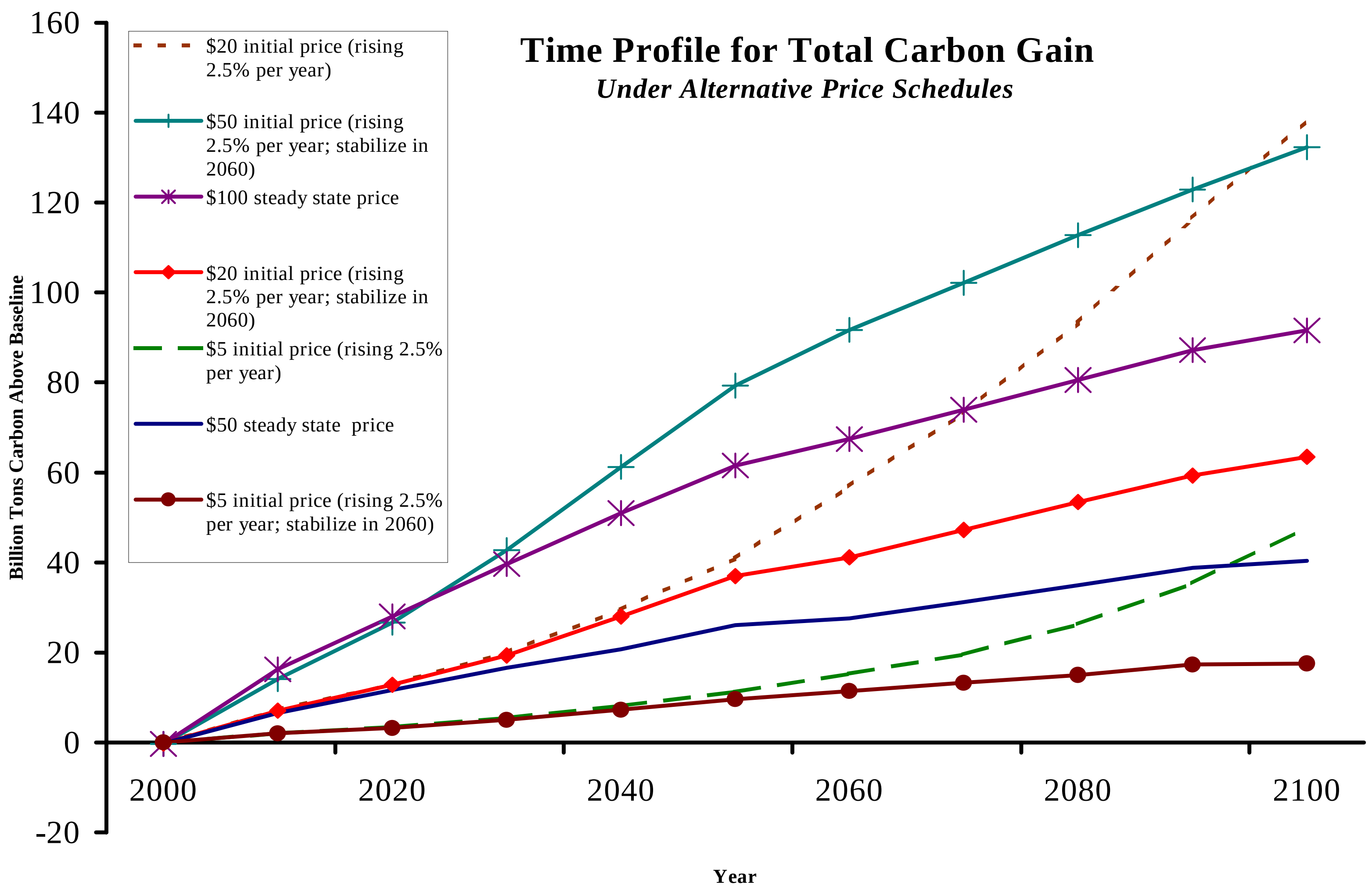


Figure 2: Three Scenarios with Seven Cases

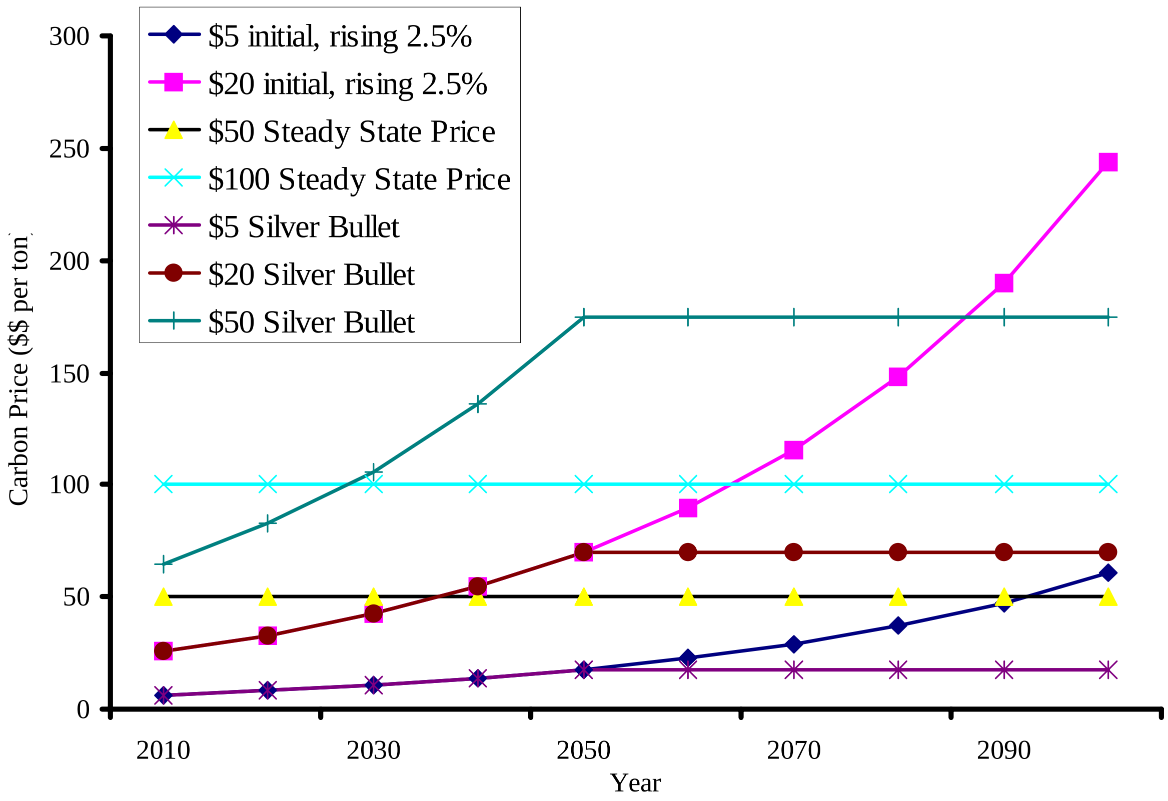


Figure 3. Global Carbon Supply Functions

Graph shows cumulative carbon functions. Under the $50 steady state (stable) price scenario, carbon sequestration is measured in the year 2100. At that time, carbon prices are $50 per ton, and total carbon sequestration is similar to that in the $5 case with rising carbon prices.

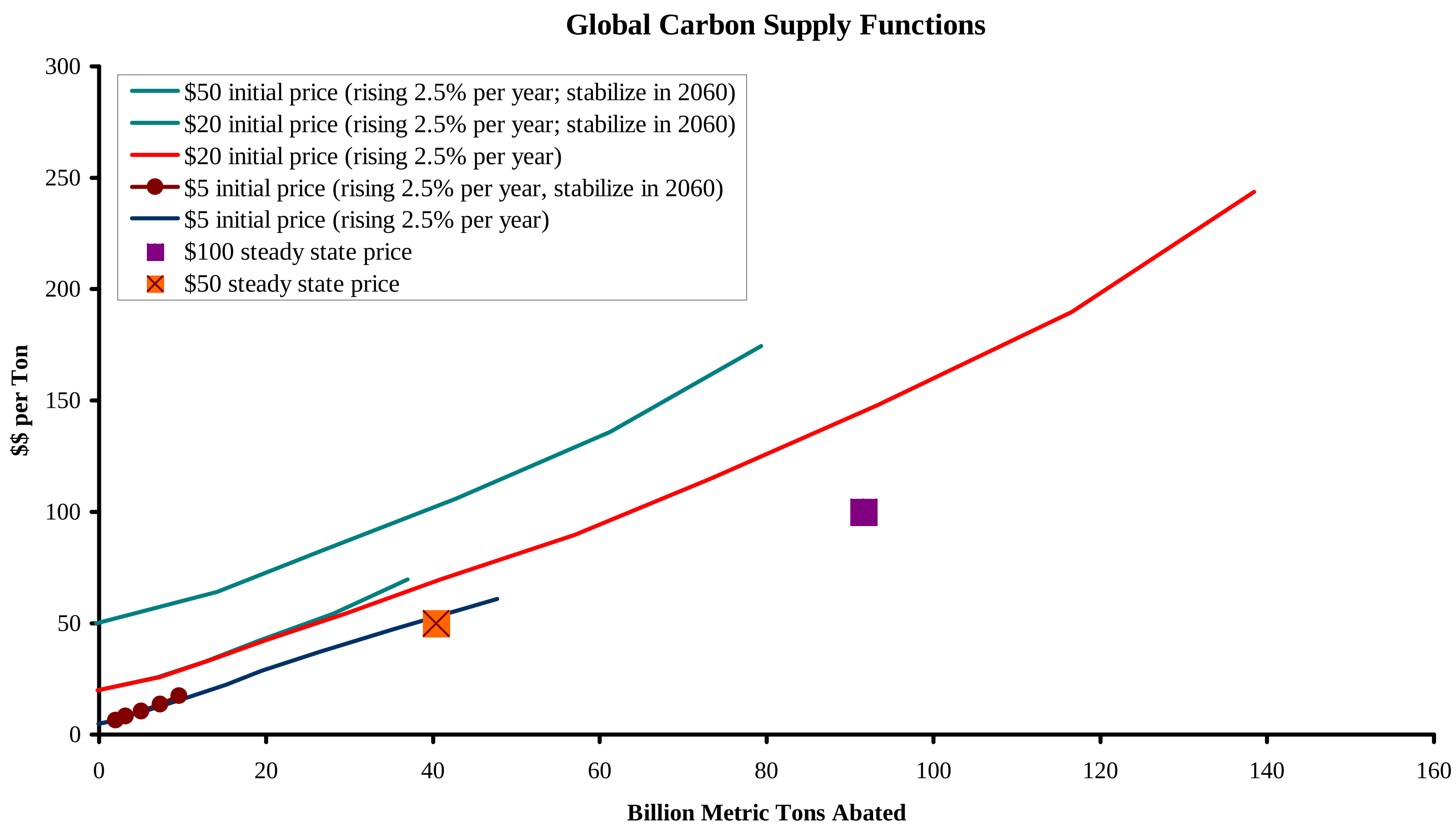


Figure 4. Global Carbon Supply Functions

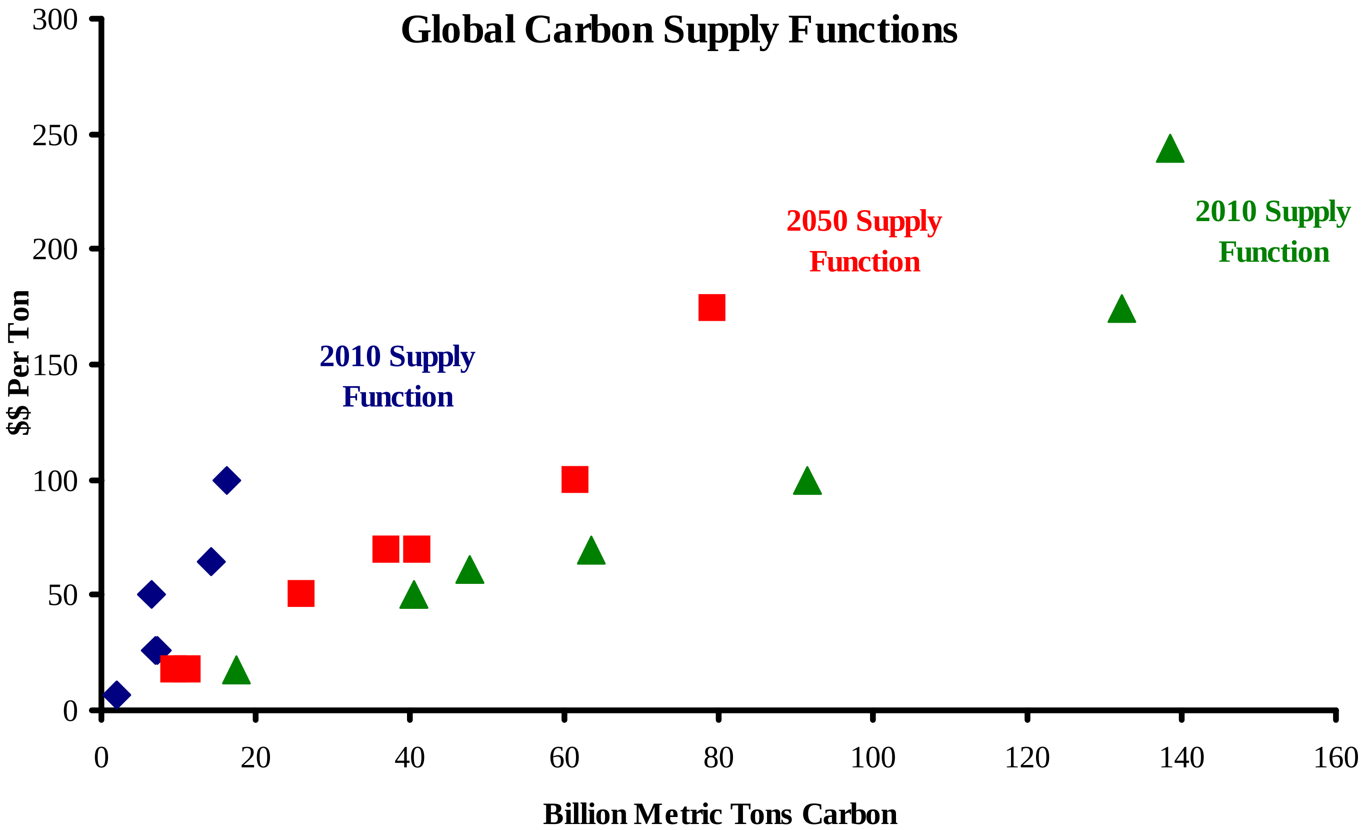


Figure 5. 2010 Carbon Possibilities

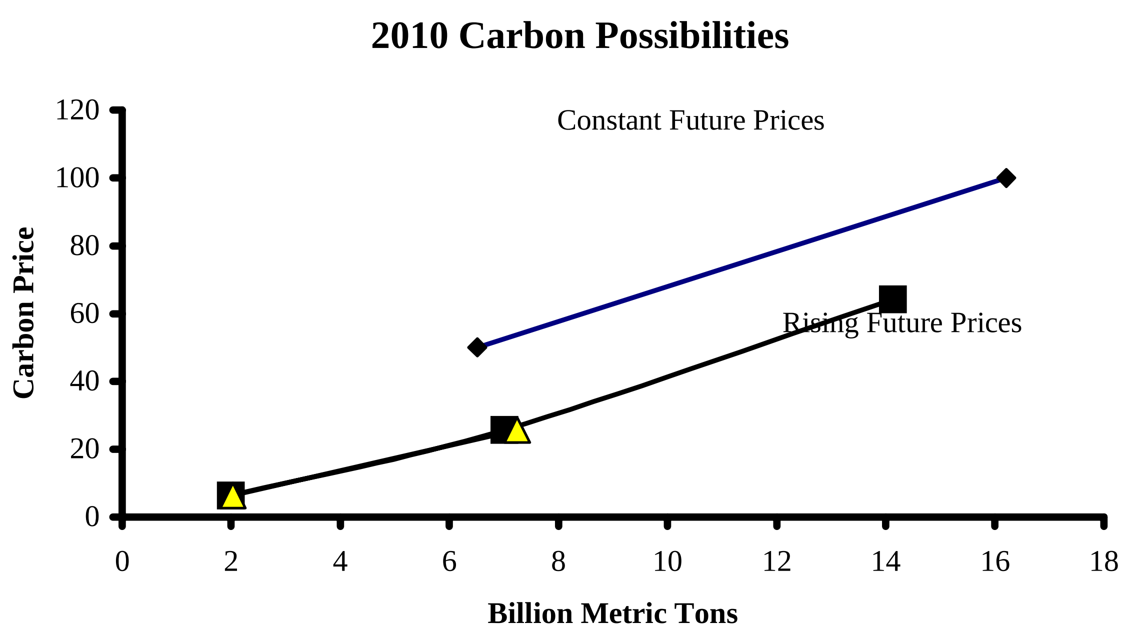


Figure 6. 2050 Carbon Possibilities

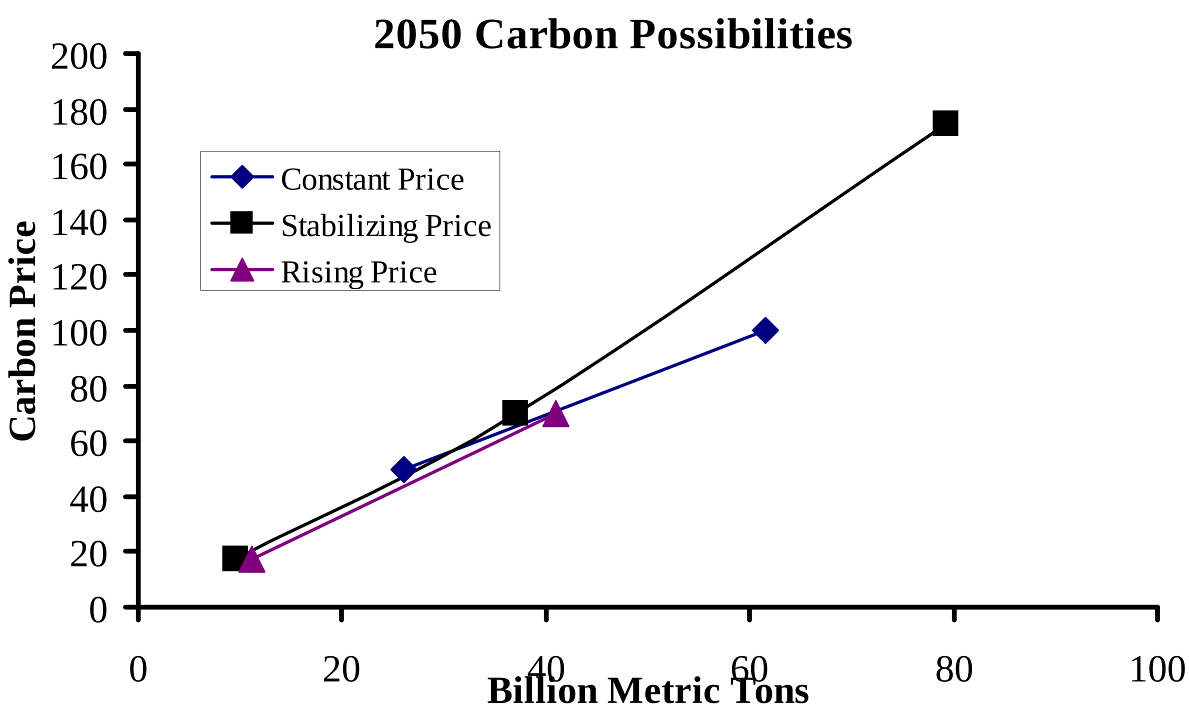


Figure 7. 2100 Carbon Possibilities

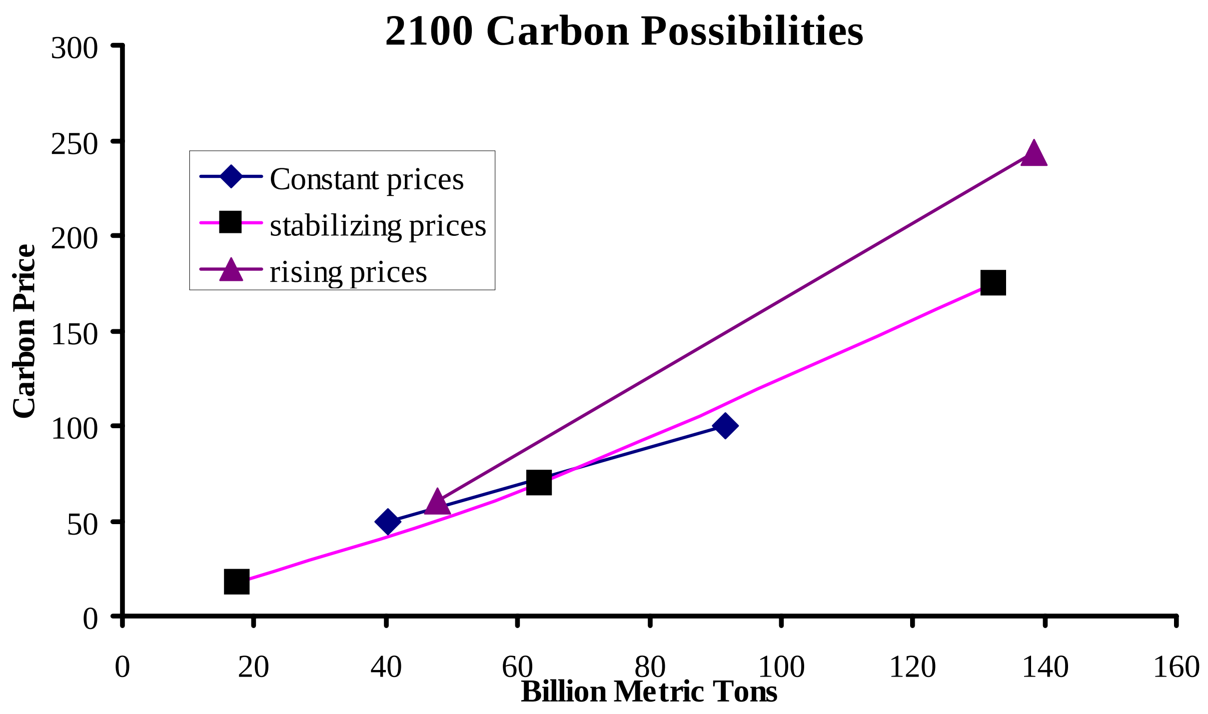


Figure 8. Carbon Storage in Forests Baseline: $5, $20 Scenarios

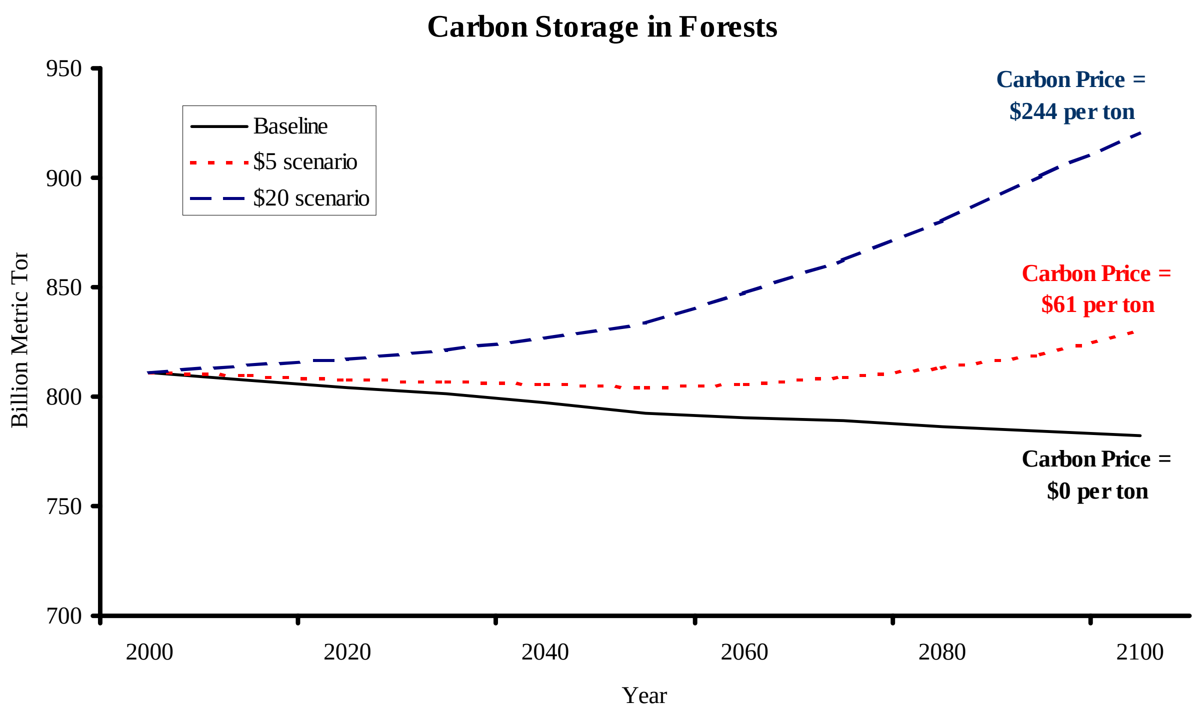
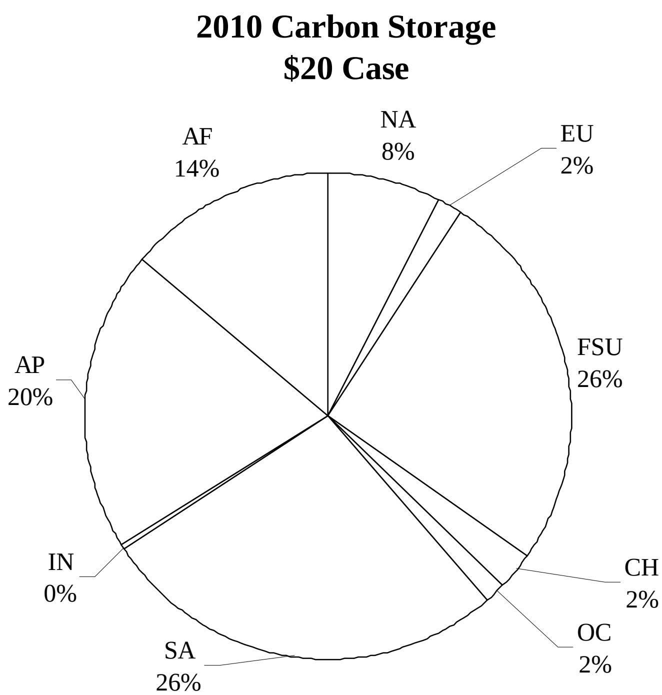


Figure 9. Regional Carbon Storage: $20 Scenario



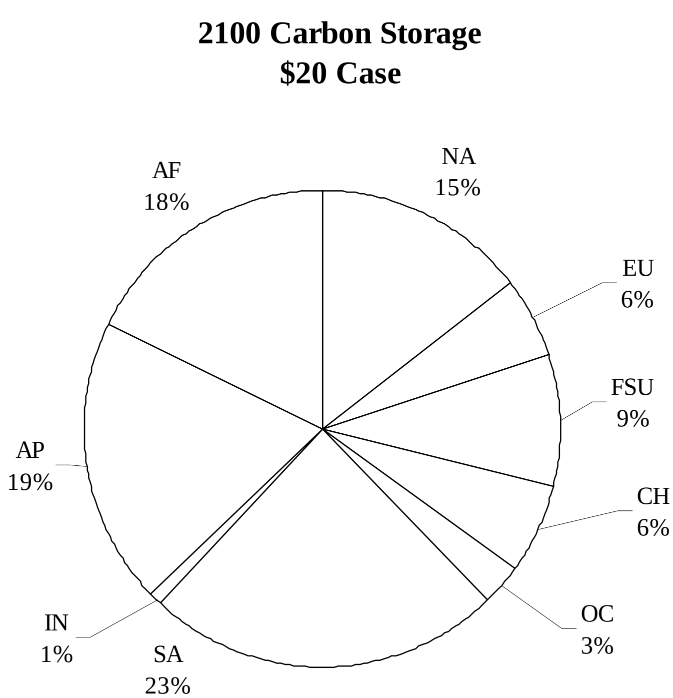
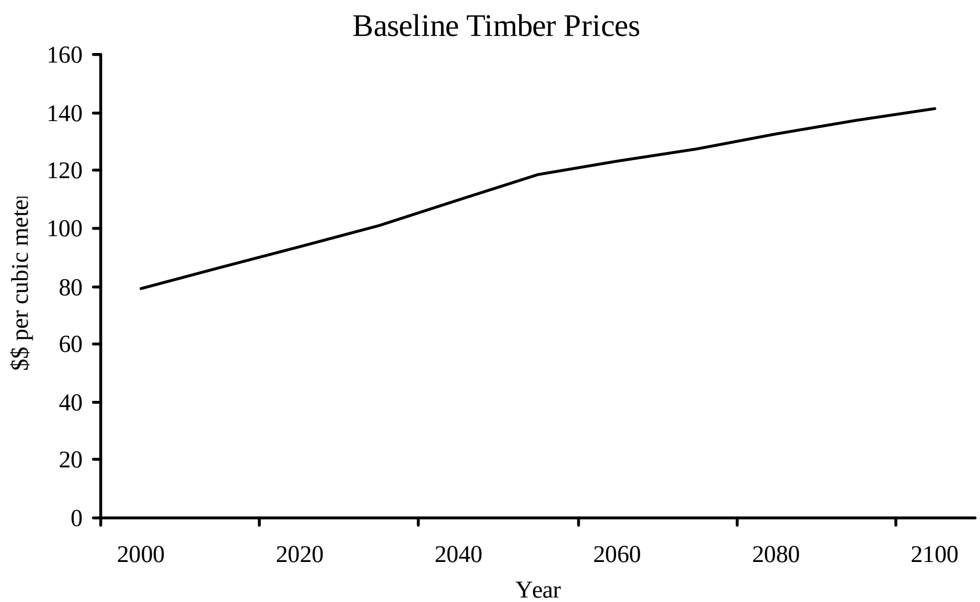


Figure 10. Baseline Prices and Carbon



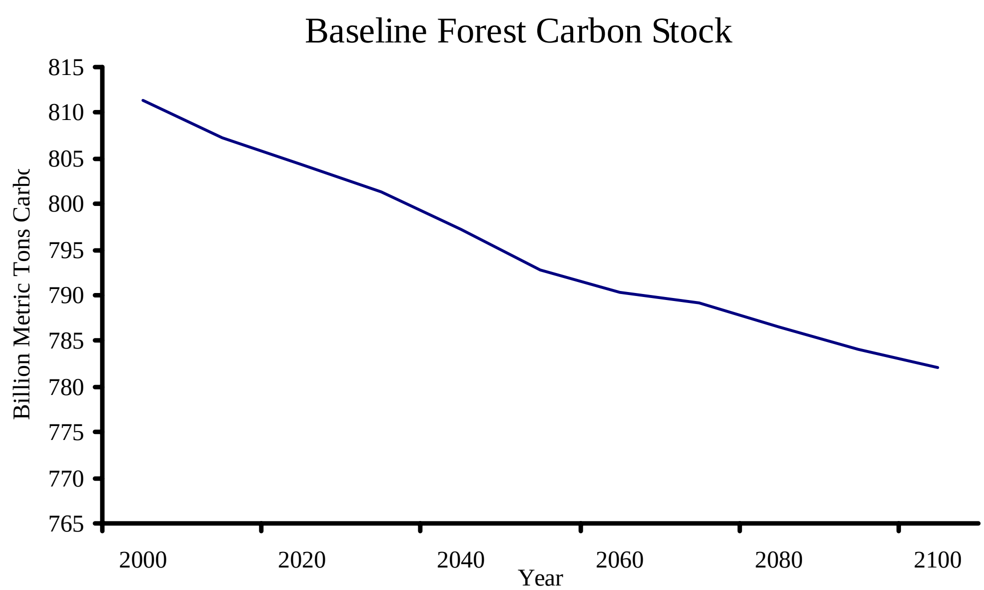


Table 1: Carbon Gains by Region and Global Total

$5 per ton initial price, rising at 2.5% to 2150 then stabilizing.

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
					Billion Metric Tons Additional Carbon Above the Baseline						
2000	5.00	-0.02	-0.06	0.04	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.06
2010	6.42	0.28	0.80	-0.08	0.34	0.07	0.00	0.02	0.32	0.28	2.03
2020	8.24	0.53	0.61	0.25	0.44	0.18	0.00	0.04	0.68	0.63	3.36
2030	10.59	0.76	1.69	0.34	0.58	0.21	0.01	0.08	1.13	0.61	5.41
2040	13.59	0.40	2.85	0.31	0.78	0.35	0.01	0.06	1.73	1.59	8.08
2050	17.45	1.40	2.72	0.63	1.05	0.29	0.01	0.20	2.49	2.41	11.20
2060	22.41	1.43	3.99	0.55	2.06	0.48	0.07	0.18	3.99	2.49	15.24
2070	28.77	1.56	4.69	1.29	2.32	0.85	0.06	0.12	4.87	3.74	19.50
2080	36.95	2.05	7.26	1.11	2.82	0.92	0.07	0.26	6.71	5.12	26.32
2090	47.44	3.72	9.31	1.34	3.71	0.82	0.12	0.51	9.14	6.75	35.42
2100	60.91	4.68	13.35	1.71	4.03	1.35	0.18	0.45	11.78	10.19	47.72

Table 2: Carbon Gains by region and Global Total

$20 per ton initial price, rising at 2.5% per year through 2150, then stabilizing

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
		Billion Metric Tons Additional Carbon Above the Baseline									
2000	20.00	0.00	-0.10	0.05	-0.08	0.00	0.00	0.00	-0.04	-0.02	-0.19
2010	25.68	0.55	1.96	0.11	1.86	0.17	0.03	0.11	1.44	1.01	7.24
2020	32.97	1.49	3.34	0.49	1.54	0.30	0.05	0.20	3.29	2.24	12.94
2030	42.34	3.15	5.03	0.89	2.00	0.49	0.09	0.30	4.70	3.30	19.95
2040	54.37	2.90	7.55	1.08	2.53	1.80	0.14	0.43	7.79	5.29	29.51
2050	69.81	4.80	10.54	1.73	3.60	1.00	0.21	0.50	10.36	8.20	40.94
2060	89.63	6.18	14.40	2.24	4.83	1.84	0.35	0.74	15.20	11.20	56.98
2070	115.09	8.51	19.04	3.66	6.92	3.83	0.77	0.97	14.00	15.65	73.35
2080	147.78	13.54	23.48	4.53	7.71	5.79	0.73	1.55	18.48	17.46	93.27
2090	189.75	17.72	29.19	5.00	9.44	6.84	0.98	1.96	24.54	20.89	116.56
2100	243.65	20.12	33.54	7.64	12.06	8.57	1.19	3.93	26.93	24.44	138.42

Table 3: Carbon Gains by region and Global Total

$50 per ton stable carbon price

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
				Billion Metric Tons Additional Carbon Above the Baseline							
2000	50	0.02	-0.10	0.05	-0.09	-0.02	0.00	0.00	-0.05	-0.02	-0.21
2010	50	0.40	2.17	-0.13	0.67	0.33	0.01	0.11	1.82	1.13	6.51
2020	50	0.99	3.33	0.29	0.77	0.21	0.01	0.18	3.42	2.44	11.64
2030	50	1.92	4.44	0.34	0.50	1.05	0.01	0.23	5.27	2.81	16.57
2040	50	2.42	6.14	0.55	1.05	0.10	0.01	0.27	5.86	4.32	20.72
2050	50	1.99	7.31	0.59	0.94	0.40	0.00	0.21	8.89	5.71	26.04
2060	50	3.37	8.31	0.67	1.38	0.57	0.00	0.30	7.16	5.77	27.53
2070	50	1.40	9.83	1.39	1.09	1.74	0.25	0.27	8.36	6.89	31.22
2080	50	2.88	11.65	1.26	1.06	1.13	0.02	0.31	8.39	8.24	34.94
2090	50	3.90	12.47	0.79	1.47	0.38	0.01	0.29	10.98	8.47	38.76
2100	50	3.02	14.03	1.04	1.23	0.45	0.00	0.32	10.57	9.74	40.40

Table 4: Carbon Gains by region and Global Total

$100 per ton stable carbon price

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
		Billion Metric Tons Additional Carbon Above the Baseline									
2010	100	1.85	4.44	0.50	2.86	0.76	0.09	0.21	2.86	2.64	16.21
2020	100	3.41	7.77	0.91	2.91	1.09	0.13	0.42	5.83	5.52	27.99
2030	100	5.57	11.06	1.17	2.76	1.88	0.17	0.63	8.38	8.04	39.66
2040	100	6.00	14.19	1.61	3.35	3.03	0.23	0.75	11.02	10.81	50.99
2050	100	7.39	16.62	1.97	4.12	2.70	0.30	0.98	14.50	12.94	61.52
2060	100	9.08	18.29	2.34	5.11	2.38	0.40	0.63	15.48	13.75	67.46
2070	100	6.67	19.56	3.72	6.95	3.87	0.76	0.58	16.40	15.42	73.93

2080	100	10.68	21.86	4.08	6.75	5.39	0.75	0.70	14.06	16.34	80.61
2090	100	12.28	24.16	3.74	7.92	5.65	0.52	0.82	14.97	17.18	87.24
2100	100	12.14	26.41	4.72	9.16	3.53	0.40	1.04	15.19	19.02	91.61

Table 5: Carbon Gains by region and Global Total

$5 per ton initial price, rising at 2.5% to 2060, then stabilizing

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
					Billion Metric Tons Additional Carbon Above the Baseline						
2000	5	-0.02	-0.06	0.04	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.06
2010	6	0.28	0.80	-0.09	0.33	0.07	0.00	0.02	0.32	0.26	1.99
2020	8	0.55	0.48	0.24	0.42	0.18	0.00	0.04	0.67	0.58	3.16
2030	11	0.71	1.59	0.31	0.54	0.20	0.01	0.07	1.10	0.48	5.01
2040	14	0.78	1.98	0.40	0.71	0.33	0.01	0.06	1.65	1.38	7.30
2050	17	1.19	2.35	0.55	0.90	0.25	0.00	0.09	2.24	2.01	9.58
2060	17	1.07	2.68	0.48	1.61	0.41	0.05	0.15	3.24	1.76	11.45
2070	17	1.03	3.32	0.55	1.67	0.65	0.02	0.09	3.31	2.56	13.20
2080	17	0.97	3.64	0.77	1.79	0.63	0.01	0.08	3.96	3.08	14.93
2090	17	1.14	4.31	0.68	2.35	0.39	0.01	0.13	5.19	3.08	17.28
2100	17	1.21	4.80	1.05	2.33	0.60	0.01	0.09	3.35	4.05	17.49

Table 6: Carbon Gains by region and Global Total

$20 per ton initial price, rising at 2.5% per year through 2060, then stabilizing

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
					Billion Metric Tons Additional Carbon Above the Baseline						
		-			-						
2000	20	0.01	-0.10	0.05	0.08	0.00	0.00	0.00	-0.02	-0.02	-0.18
2010	26	0.68	1.92	0.04	1.83	0.17	0.02	0.11	1.25	0.99	7.01
2020	33	1.17	3.23	0.44	1.94	0.29	0.04	0.19	3.31	2.20	12.81
2030	42	3.10	4.76	0.57	1.95	0.43	0.06	0.28	4.99	3.17	19.31
2040	54	2.61	7.19	0.90	2.64	1.63	0.09	0.38	7.22	5.38	28.04
2050	70	3.39	9.09	1.19	3.29	1.28	0.12	0.38	11.44	6.82	37.00
2060	70	5.49	10.74	1.40	4.05	1.42	0.16	0.47	9.82	7.63	41.18
2070	70	4.35	12.91	2.15	4.25	2.62	0.46	0.44	11.11	8.92	47.21
2080	70	6.42	15.18	2.20	4.17	2.93	0.31	0.45	11.20	10.55	53.41
2090	70	6.94	16.44	1.97	5.53	3.23	0.33	0.45	12.98	11.43	59.30
2100	70	7.10	18.30	2.48	5.68	2.28	0.32	0.42	13.87	13.00	63.45

Table 7: Carbon Gains by region and Global Total

$50 per ton initial price, rising at 2.5% per year through 2060, then stabilizing

Year	CPrice										
	$$ per ton	NA	SA	EU	FSU	CH	IN	OC	AP	AF	total
		Billion Metric Tons Additional Carbon Above the Baseline									
2000	50	0.03	-0.14	0.00	-0.12	-0.02	0.00	0.00	-0.07	-0.04	-0.36
2010	64	1.28	3.71	0.51	2.67	0.74	0.09	0.20	2.73	2.20	14.13
2020	82	3.54	6.99	1.18	2.79	0.75	0.15	0.44	5.45	5.34	26.63
2030	106	6.24	11.03	1.42	3.57	2.00	0.22	0.75	8.92	8.58	42.73
2040	136	7.88	14.94	2.10	4.18	3.68	0.33	1.11	14.64	12.36	61.22
2050	175	10.93	18.03	2.88	5.53	4.67	0.46	1.50	19.55	15.80	79.35
2060	175	13.94	20.39	3.28	6.88	5.93	0.61	1.84	21.51	17.35	91.73
2070	175	12.20	22.21	4.89	8.68	7.90	1.12	2.38	22.74	20.08	102.20
2080	175	16.09	25.59	5.12	9.47	9.86	1.07	1.83	23.02	20.66	112.71
2090	175	18.72	27.37	5.75	10.68	10.58	1.43	1.53	24.36	22.48	122.90
2100	175	21.60	28.43	6.76	11.53	10.41	1.33	1.90	27.97	22.38	132.31

Table 8: Total Carbon Storage – 2000: Comparison of Estimates

	Billion Metric Tons	
	This Study 2000	Dixon et al. (1999) ~2000
NA	160	277
EU	25	34
FSU	207	323
CH	33	33
OC	5	51
High Latitude	*429*	*718*
SA	218	229
IN	2	
AP	49	84
AF	114	115
Low Latitude	*382*	*428*
Global	**811**	**1146**

Table 9: Average Annual Changes: Baseline Estimates – to the year 2100

	Average Annual Change by 2100			
	Area	Forest C	Mkt C	Total C
	10^3 ha	10^6 m.t.	10^6 m.t.	10^6 m.t.
NA	227	-20	34	14
EU	62	4	21	25
FSU	54	-18	12	-6
CH	-21	-8	10	2
OC	88	16	7	23
High Latitude	408	-26	84	58
	0			
SA	-1477	-175	33	-142
IN	13	1	2	3
AP	-505	-108	18	-91
AF	-1150	-129	9	-120
Low Latitude	-3119	-411	62	-350
Global	-2710	-438	146	-292

Brown, 1998

878 Billion mt