Pulp Non-Fiction: Dynamic Modeling of Industrial Systems

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ABSTRACT

Changes in input and emissions intensity profiles of industry result from change in economic structure, input substitution or technological change. Economic decision-making drives each component of change and is influenced by economic, technical and regulatory realities within which the industrial system operates. Furthermore, changes in input flows, are heavily shaped by the structure of the already installed capital stock, current investment, depreciation and previous investment behavior, which greatly limits the rate by which an industry can change. In addition, most mature industries exhibit path dependent behavior and a combination of investment learning and learning-by-doing. Consequently, to understand and facilitate change in input and emissions intensity, requires that attention is paid to the structure of the capital stock and its impact on changes in input use and pollutant emissions, in addition to learning and current investment behavior.

This paper presents a conceptual and modeling framework that combines engineering and econometric analysis with detailed representation of an industry's capital stock structure. The framework captures both embodied and disembodied technological change, in addition to learning and path dependency. Descriptive equations are entered into dynamic simulation software, simulating industrial behavior using non-linear differential equations. One case study is presented on the US pulp and paper industry, which demonstrates significant capital inertia the limited impact of price driven input substitution in the absence of stock turnover or retrofits on improvements in energy, material or carbon efficiency.

Introduction

In 1998 more than 100 leading international industry experts called for less aggregated analytical economic modeling and increased presence of engineering-economic analysis in the context of climate change policies (Dowd and Newmann 1999). More recently at the 2003 ACEEE Summer Study, numerous industry and modeling experts signed a statement expressing concern for the status of current modeling practice in energy forecasting and policy analysis, which "tends to reinforce the status quo and serve to constrain the development of innovative policies" (see http://www.aceee.org/energy/manifesto.htm). The manifesto urged increased use of scenario analysis, better characterization of technology and behavior and more transparent modeling tools. Such analysis and tools would enable, for example, the response of the entire industrial system to changes in the economic environment (e.g. due to policy) and thus the assessment of unexpected costs and benefits (co-benefits) of a management decision/policy. Such unexpected costs could be, for example, an increase in material intensity due to a change in energy policy, and unexpected benefits could be an increase in productivity (Worrell et al 2003). All of this should enable more realistic analysis of future energy or material use and of course waste flows in addition to enable analyses of the full response of a system to changes in its economic environment (e.g. due to policy). The framework presented in this article aims to answer those calls.

The remainder of the paper is structured as follows: The following section discusses the main economic drivers of industrial change in the context of capital vintage dynamics and energy and material flows. The third section briefly describes an implementation of the modeling framework using a case study of the US pulp and paper industry, beginning with a description of the system and system boundaries, followed by a brief description of the model itself. The fourth section presents highlights from model parameterization and basic simulation results in the context of the importance of capital vintage dynamics and the impact of energy prices. The article concludes with a discussion of the relevance of the approach and findings for energy, material and climate change policy.

Drivers of Industrial Change

Technological Change, Structural Change, and Substitution

Changes in the average input intensity of energy and material flows by process are commonly decomposed into those caused by technological change[1], structural change and input substitution (Farla et al. 1997). Each component is affected by different economic and engineering factors, such as input prices and structure of the capital stock.

Technological change can either be embodied or disembodied, where embodied change only influences new capital vintages and disembodied change influences the efficiency of already installed capital (Meijer 1994, Berndt et al 1993, Davidsdottir 2004). Embodied technological change implicitly captures invention, innovation and diffusion through which the innovated invention becomes part of the capital stock via either replacement or expansion investment (Schumpeter 1939). Embodied technological change requires significant direct and indirect capital investments. Direct investments (facilitating diffusion) are undertaken by the industry actually using the capital. Indirect investments are made by those participating in earlier stages (invention and innovation) through e.g., R&D expenditures. R&D expenditures have much impact on the character (e.g. efficiency) of available new capital and usually occur outside of the industrial system in question (Scherer 1982). Because embodied change occurs through new capital investment, it only influences the input efficiency of youngest capital vintages.

Capital vintage is defined based on the year in which investment occurred. The size of each vintage is a function of both expansion and replacement investment – which both add to the newest vintages of the productive capital stock and together establish the new vintage. The size of "existing" vintages declines as a function of replacement investment. Replacement investment or retrofits thus alter the structure of the capital stock, and reduce the size of an existing vintage, but add to the size of new vintages. As a result, assuming that new capital is more efficient than "existing capital" replacement investment will reduce input intensity and reduce total input use. On the other hand, expansion investment increases the size of the capital stock, increases total input use and incrementally reduces input efficiency. Diffusion of new technologies is influenced by economic factors such as input prices in addition to learning. Furthermore, the extent to which diffusion and embodied technological change occurs is highly path dependent (Arthur 1994, Unruh 2000, Kuper and Soest 2003). Choices made early on in the development of an industry gradually rigidify (technology lock-in), defining the future technology trajectory as a function of

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[1] Technological change is defined here as a reduction in the use of an input, holding other inputs and output constant. Structural change can of course change the input use, but at the same time will change the output mix.

the structure of the existing capital stock. Capital inertia further reduces the rate of technological change and efficiency improvements. If an industry is mature, capital intensive and dominated by early-vintage capital stock, capital vintage structure can act as a significant deterrent to change in response to altered external economic or environmental conditions (Davidsdottir and Ruth 2004)

Disembodied technological change only influences "older" vintages and is defined as low - or no - cost operational changes improving input efficiency of the already existing capital stock (Ross 1991). Such changes can be in the form of improved housekeeping practices and typically do not require a substantial investment in fixed capital structures. Learning-by-doing plays a central role in disembodied change as enterprises gain experience in operating equipment, and thus efficiency potentially improves after capital is installed (Meijer 1994, Ruth, et al. 2004, Davidsdottir and Ruth 2004).

Structural change in industrial system analysis is defined as a change in the output mix and is driven by demand and other factors in an industry's economic environment, but is limited by the vintage structure of the capital stock. Structural change, for example, in the paper industry could encompass a shift away from producing newsprint towards producing more printing and writing papers. Because fiber and energy requirements differ substantially for those two products– they are produced using different pulping processes– such a shift would influence both energy and material intensity as well as the character of those flows (Ruth and Harrington 1998, Davidsdottir 2004).

Input flows and input efficiency also change in response to direct input substitution. Substitution is defined as an increase in the use of one input and a decline in another one, holding output constant. It can be equally feasible for new and old vintages (putty-putty), only feasible for new vintages (putty-clay) or not feasible for neither new nor existing vintages (clay-clay). The appropriate choice of the characterization of substitution possibilities in most cases depends on the level of aggregation and in the case of industrial system analysis that choice in most cases is putty-clay. Again, this links not only technological and structural change to capital vintage, but also substitution. So even if changes in input intensity are always in some way linked to behavioral or economic parameters such as consumer preferences and input prices, they ultimately are defined by the structure and size of the capital stock. Those relationships are captured using capital vintage modeling.

Capital Vintage Modeling

Capital vintage models were first developed in the 1950s and 1960s (e.g. Kaldor and Mirrlees 1962) and have recently been used to analyze energy flows in industrial systems (Ruth et al. 2004, Davidsdottir and Ruth 2004, Davidsdottir 2003, 2004). Capital vintage models capture the age structure of the capital stock and its associated age-specific attributes such as size, rate of capital replacement, input efficiency and input substitution possibilities. For example, an older vintage is likely to require a larger amount of input materials and energy to produce the same amount of physical output compared to a new vintage. An industrial system "evolves" as the capital stock changes via investment, through either expansion of the capital stock (expansion investment) or through the gradual replacement of old, obsolete, or worn out structures (replacement investment). The expansion of a capital stock will, *ceteris paribus*, increase the use of input materials and slightly improve material and energy efficiency– given that the industry invests in more efficient capital. Again assuming the industry invests in more efficient capital, replacement investment will more extensively increase energy and material efficiency and help keep constant (or reduce) total use of material and energy inputs. Thus, the "evolution" of a mature industrial system changes the efficiency of material and energy use, which combined with output levels, capacity utilization and structure of the output, determines the size of total material and energy flows. The capital vintage framework used in this study expands the vintage models developed by Meijer (1994), Ruth et al. (2004) and Davidsdottir and Ruth (2004). The following section describes the implementation of this framework for the US pulp and paper industry (NAICS code 322), which is briefly described in the section below.

The Model

General System Description

The organizational structure of the US pulp and paper industry can broadly be divided into three tiers: pulp production, paper and paperboard production and finished products production (Smith 1997). The industry is regionally heterogeneous, mature, vertically integrated and best represented by a competitive market structure (Davidsdottir 2004). For this study, the industrial system is disaggregated by census region to capture regional heterogeneity. Production within each of the eight regions is disaggregated into four paper products (newsprint, tissue, printing and writing, packaging and industrial paper), and four paperboard products (kraft paperboard, bleached kraft paperboard, semichemical paperboard and recycled paperboard).

The industry is one of the most capital-intensive industries in the United States with capacity-utilization-rates averaging over 90%. Low profit margins and high capital intensity necessitate the industry to operate at almost full capacity, and any halt to production, for example, to update antiquated equipment such as to improve energy efficiency may result in bankruptcy. Hence, updates in energy efficiency are often realized as side-results to changes in production capabilities (Davidsdottir 2004). The framework captures regional structure of the capital stock, and region specific rates of expansion and replacement investment.

Material inputs primarily consist of waste or virgin fibers with a wastefiber-utilization rate (WUR) averaging 35%, yet regionally varying from 20 – 54% (see Table 1). The framework captures the regional flow of materials by type. Virgin materials flow from forestry operations to the pulp and paper making process and flow out of the system as wastepaper. The model captures the flow of domestically produced wastepaper and traces its fate - either into the industrial system again or into the solid waste stream. After wastepaper ends up in the solid waste stream, it either is incinerated, or put into landfills.

The industry selfgenerates over 50% of its energy needs (mostly derived from black liquor, the liquid residual from the chemical pulping process). However, fuel intensity and fuel mix are regionally heterogenous, with selfgeneration ranging from 29% - 63% (Table 1). Table 1 illustrates that production in regions that rely on virgin fibers is, on average, more intensive in energy use, while selfgenerated energy supplies a larger proportion of total energy needs. Thus energy intensity of purchased fuels is higher in regions that have high WUR than those that use virgin fibers for chemical pulping. The framework captures region specific total energy use by energy type, disaggregated into selfgenerated energy and six different purchased fuels.

Waste flows in this implementation of the framework are defined as flows of carbon – both from the burning of fossil fuels, as well as methane and carbon dioxide emissions from paper decay in landfills, in addition to emissions from waste-paper incineration.

Table 1. Regional Average Energy Intensity, Fractional Share of Selfgenerated Energy and Waste Paper Utilization Rates in 1998.

Census Region	Average energy intensity (million BTUs/ton output)	Selfgenerated energy - % share	Wastepaper Utilization rates (%)
New England	21.54	47.9	0.36
Mid Atlantic	18.80	29.3	0.54
East North Central	20.34	37.5	0.50
East South Central	34.16	61.5	0.22
Mountain and Pacific	24.82	42.6	0.42
South Atlantic	42.89	63.0	0.29
West South Central	34.16	61.5	0.22
West North Central	20.34	37.5	0.50

Source: AF&PA various years

Model Structure

The model contains the following five interacting modules:

- **Production module** – simulates regional production levels/growth by product type using a reduced form production function where output is a function of lagged input prices, regional income discounted by distance to a demand region, lagged production levels and subject to total installed regional productive capacity (Kaltenberg and Buongiorno 1986).
- **Physical vintage module** – describes the regional size of each capital vintage initially broken into regional annual investments back to 1950 that still are potentially productive. Changes in the size of existing vintages is assessed using physical perpetual inventory where the size of each new vintage (gross investment) is a function of replacement and expansion investment which both are econometrically estimated. Replacement investment by definition equals the proportion of gross investment that directly replaces retired and depreciated capital. Vintage specific replacement rates are econometrically estimated using a Gumpertz curve, and are a function of the age of capital (thus vintage specific) and input prices.
- **Input intensity module** – each vintage as it enters the capital stock is assigned a set of vintage and region specific input intensity parameters. The input intensity module thus relates the input intensity of each input type by vintage, to the size of each vintage, giving the total intensity of the capital stock, and, combined with the production module, gives total use of each input type. The input intensity of each new vintage (embodied change) depends on process specific relative energy intensities of new to old capital, the relative importance of each process in total production and the weighted average embodied

intensity of existing capital[2] in addition to the size of new investment. This captures both the impact of path dependency and learning on future direction and speed of embodied change. Input intensity also changes as a function of disembodied change, which is econometrically estimated as a function of learning-by-doing and input prices.

- **Input mix module** – breaks total energy and fiber use into vectors of different energy and fiber types and simulates changes in the input mix, i.e. the switch between process fuels and from virgin to waste fibers. The switch between energy types is econometrically estimated and simulated as the simultaneous change in the fractional shares of each energy type, driven by relative prices and output mix. The switch between waste and virgin fibers is estimated as an incremental movement of the fractional share of wastepulp towards (or away from) region specific maximum waste-paper utilization rates (Ruth and Harrington 1998). The path towards that maximum is estimated econometrically using the Fisher and Pry (1971) technology substitution model and driven by input prices, cumulative wastepaper use and recycling legislation. To achieve mass balance in the system waste-fibers are assumed to only originate in US produced sources and thus produced and used paper products go back into the potential pool of fibers with a one year time lag – where wastepaper use cannot exceed last years production of paper. The wastepaper that is not recycled is either incinerated or landfilled.
- **Greenhouse gas emissions module** – describes emissions of methane and carbon dioxide from landfilled paper using the EMCON Methane Generation Model (EMCON 1982) and emissions from wastepaper incineration and emissions from the use of process fuels by type using fixed emissions coefficients.

Each module exists for each census region, and contains region-specific equations, which are solved simultaneously for each future year to yield trajectories for system inputs and outputs. Parameter estimates are based on time-series analysis of 27 years of historical data (1972 – 1998), vintage-based capital analysis and engineering/physical information.

Parameter Estimation and Simulation Results

Parameter Estimation

After estimating all necessary parameters, either using econometrics or engineering estimates, each equation is entered into the dynamic simulation software STELLA Research© and run simultaneously to examine overall industrial behavior. In the case of econometrically estimated parameters, theory and econometric principles guide parameter choice. Only statistically significant parameters enter the simulation model and all are subject to extensive regression diagnostics such as the Lagrange multiplier tests for heteroscedasticity, serial correlation as well as augmented Dickey Fuller tests for unit roots and cointegration.

The parameter estimation results revealed the following: The price of energy plays a central role in decision-making in the pulp and paper industry. For example, energy prices were instrumental in shaping production and investment decisions, in addition to be the main driver behind input substitution. The output elasticity of energy price differed substantially between

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[2] Weighted by the relative importance of each vintage in total production.

regions and output types. For example, in regions where virgin fibers are the prevalent fiber type the energy price elasticity of aggregate production of paper and paperboard was low or insignificant, with energy price elasticities of recycled paperboard significantly higher than in regions with high WUR's. In regions that already had high WUR, energy price elasticity of aggregate production and recycled paper products was similar and high. This indicates that an increase in energy prices, for any reason, on the one hand is likely to disproportionately disadvantage paper production where wastepaper is the main fiber input where production is expected to substantially decline. But on the other hand in regions with low WURs the industry is likely to shift towards processes that enable increased selfgeneration of energy and that rely on virgin fibers rather than to reduce production volume. Because chemical pulping, which enables selfgeneration of energy and relies on virgin fibers is more energy intensive than wastepaper pulping, such an increase in energy price is likely to increase total energy intensity in the industry, but at the same time reduce purchased energy intensity and thus reduce energy expenditures.

Expansion investment is significantly negatively affected by energy prices, and since embodied improvements in energy intensity often are associated with expansion of the capital stock, the rate of embodied technological change as a result of expansion investment, is expected to decline. An increase in energy prices increases the rate of replacement for "older" capital, but reduces the rate for younger capital. Given the capital vintage structure of the US pulp and paper industry, an increase in energy price will slightly increase the average rate of replacement investment. Thus overall, an increase in energy prices will reduce the scale of expansion investment and shift the investment that occurs towards processes that enable selfgeneration of energy, and either increase or decrease replacement investment depending on the structure of the capital stock. Consequently, it is uncertain that an increase in energy prices will facilitate a decline in total energy intensity via embodied technological change, but it is likely that the intensity of purchased fuels will decline. Disembodied technological change is significantly and positively affected by learning-by-doing and by energy prices. Yet, an increase in energy prices can (depending on region) reduce production volumes, and thus reduce the rate of learning and thereby negatively affect disembodied technological change. However the price effect overwhelms the learning effect and thus an increase in energy prices facilitates an increase in the rate of disembodied technological change in all regions – but of course more so in those whose production volume is not affected by higher energy prices.

Substitution between energy types is significantly affected by relative energy prices, and the fractional share of chemically produced pulp has significant and positive impact on increased share of selfgenerated energy in total energy use. Energy prices also significantly influence the fiber mix, whereas increase in energy prices slows down the expansion to increased waste-paper use. Overall, an increase in regional energy prices is seen to reduce WURs, stimulating an increase in the share of virgin fibers and an increase in the share of selfgenerated energy. This result is most likely caused by the fact that firms which use recycled fibers as their main fiber source must purchase most of their energy and are not able to sell (on net) energy into the grid, unlike those that use virgin fibers and chemical pulping processes. Thus as energy prices increase, processes that use waste-fiber or mechanical pulping are harder hit than those that uswe chemical pulping. Even if waste-fiber pulping in total is less energy intensive than the chemical pulping of virgin fibers, it is more energy intensive when only purchased energy needs are accounted for.

Simulation Results

One of the expected benefits of this particular modeling approach is to capture explicitly the impact of embodied and disembodied technological change and the impact of capital inertia and investment behavior on the effectiveness of different tools central to the environmental and energy policy debate. Other benefits such as accounting for tradeoffs between energy and materials have been extensively discussed elsewhere (Davidsdottir, 2003). The model is run from 2000 until the year 2020 creating a base case, a high GSP (Gross State Product – which captures economic activity at the US State level) high growth case **(5% over base growth rate)** and a low growth case **(5% under base growth rate)**, using exogenously forecasted data of regional input prices (EIA various years, AF&PA various years) and regional income or GSP (BEA various years). The base case results indicate the following for energy and material use, energy and material intensity, carbon emissions and carbon intensity.

Total energy intensity (or total carbon intensity) overall is declining in all regions, with the intensity of purchased fuels (or net carbon intensity) declining faster than the intensity of selfgenerated fuels due to the continued shift towards selfgenerated energy. This implies reduced reliance on purchased energy at the national level. Despite the decline in energy intensity, total energy and material use, use of selfgenerated fuels and purchased fuels are all expected to increase at national and regional levels, if production levels continue to increase. As expected and as indicated by estimated parameters, output levels and output mix significantly influence total carbon emissions and carbon intensity because of the interdependence between production of specific outputs and their fuel and material requirements.

Change in energy intensity is influenced by both embodied and disembodied technological change, but on average, energy intensity is expected to change as a result of technological change, at a rate of 0.3 – 0.7% annually, in the base case. Embodied technological change accounts for on average 78 – 83% of total technological change, with the remainder accounted for by disembodied technological change. This indicates that in this particular industrial system, investment (either replacement or expansion) in new capital is the main driver of technological change and thus embodied technological change is an important driver in overall industrial change. This indicates that change in energy efficiency is closely linked to installed capital, which implies the importance of designing environmental and energy policies that facilitate increased capital turnover. The wide range of differing rates of technological change, represent substantial regional differences and is mostly driven by differing regional growth rates both in terms of economic growth and the growth of the pulp and paper industry within each region. A region whose industry has higher investment rates experiences faster embodied technological change, and thus exhibits a more rapid decline in energy/carbon intensity, when compared to a region that has lower levels of investment. Also, since disembodied change is significantly influenced by learning-by-doing, a region that has lower production rates experiences lower rates of learning-by doing and thus has lower rates of disembodied change. However, the long-lifetime of capital in this industrial system greatly limits the speed by which embodied technological change occurs.

Expansion investment is found to account for approximately 38 – 72% of capital investment, with the remainder accounted for by replacement investment. Over time however, base case simulations indicate that it is likely that replacement investment will increase in importance. Thus regional differences are found in capital turnover rates, with average rates ranging from 1.5 to 1.7%. Shifts between process fuels, are expected to continue, with increasing importance of selfgenerated energy and natural gas, but declining importance of residual fuel oil and coal. Of course such shifts have a larger impact on carbon intensity, than on energy intensity due to the assumed carbon neutral properties of selfgenerated energy.

Overall as indicated above, carbon intensity is expected to decline and substantial regional differences in regional paths of carbon emissions and carbon intensity are observed. Different regional developments and character of output and input mix, and thus WURs and the extension possibilities of selfgenerated energy can mostly explain this difference. Other contributing factors are regional differences in the rate of technological change that, as stated before, mostly is driven by differing regional growth rates both in terms of economic growth and the growth of the pulp and paper industry.

The model was also used to simulate the impact of a $100 increase in the cost of carbon, increasing the price of coal and residual fuel oil, compared to natural gas and selfgenerated energy. As expected, an increase in the cost of carbon was seen to drastically reduce production rates in regions heavily reliant on wastefiber inputs that incidentally are heavily reliant on coal and residual fuel oil, and result in a shift in production to regions in the South and a shift to processes that enable efficient selfgeneration of energy such as chemical pulping. Overall wastepaper utilization rates declined substantially, with a larger reduction in regions less reliant on wastepaper to begin with. This shift overall increased total fiber intensity in the industry.

On average total energy use declined substantially, mostly due to reduced production levels. But, total energy intensity on average for the US did not change in a statistically significant manner from the base case scenario. Decomposing energy intensity into intensity of selfgenerated fuels and intensity of purchased fuels, purchased energy intensity declined significantly from the base scenario, whereas the intensity of selfgenerated energy increased significantly as well. Overall, those two movements cancelled each other out, resulting in the non-significant overall change in total energy intensity. The increase in the cost of carbon overall increased slightly replacement investment, and the turnover rate of capital, but reduced significantly expansion investment, when compared to the base scenario, reducing the rate of embodied technological change. The rate of disembodied change increased as the impact of energy prices, outweigh the reduction in learning-by doing. As before, substantial regional differences were observed.

Discussion

The research presented in this article highlights numerous important issues to consider when modeling the behavior of complex industrial systems, and when assessing the impact of different policy initiatives. For instance, in the quest to increase energy or carbon efficiency, parameter estimates and simulations reveal that a price based energy/climate policy may increase the efficiency of purchased energy– directly due to *fuel switching* from purchased to selfgenerated energy, and indirectly due to a *switch* to processes that allow increased energy selfgeneration. However, such a policy may simultaneously reduce the use of the less energy and fiber intensive wastepaper pulping process, and may reduce total energy and fiber efficiency. The picture would of course look different if the industry invested simultaneously in the more energy efficient – but not yet economically efficient - black liquor gasification technology, which could transform the industry into a net energy exporter, or took advantage of the significant cost–effective energy efficiency improvement potentials that currently are available in the United States. Such investment could reduce energy use in the industry by 14-22%, which underscores the need for investment incentives to help realize this important potential (Martin et al 2000, Davidssdottir and Ruth 2004).

Regardless of the region, an increase in the rate of capital turnover is the most important factor in permanently changing energy use profiles in the pulp and paper industry (see similar conclusion in e.g. Nystrom and Cornland 2003 and Worrell and Biermans 2005). This is due to the long-lifetime of capital in the sector, low rates of capital turnover and high capital intensity. The immense capital intensity and capital inertia ensure the capital stock will change slowly and thereby only gradually improve energy, carbon and fiber efficiency. An increase in energy prices is not sufficient to overcome such capital vintage effects because the system adapts very slowly to change – and such an increase will rather facilitate fuel switching and disembodied changes in efficiency rather than the required embodied changes. Consequently, to enhance the long-term sustainability of this particular industrial system, policies need to provide investment incentives to facilitate faster turnover of old capital, which would result in permanent changes in material and energy flows and material and energy efficiency. In addition, higher rates of turnover imply higher levels of replacement investment, which indicate acceleration of diffusion of more efficient capital and an acceleration of learning without increasing total emissions. Because, in the US pulp and paper industry, investment in more energy efficient equipment usually is a side-bonus to enhanced production capacity, policies should include investment incentives for investing in more efficient capital and thereby making such investment in of itself feasible in addition to prevent a reduction in WURs if a simultaneous goal is to secure the economic viability of recycling (Davidsdottir and Ruth 2004). Such policies include investment tax rebates, demonstration projects to reduce uncertainty and incentive driven voluntary sector agreements (Worrell et al 2001). Given a continued growth in the industry without incentives to replace existing capital, technological change will remain incremental and material and energy use and carbon emissions from the pulp and paper industry will continue to increase into the foreseeable future. However, such policies are likely to go unnoticed if the modeling tools used for policy analysis do not enable integrated analysis of input and waste flows in addition to the capital structure and investment behavior in industry.

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