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THE ECONOMIC THEORY OF PRODUCTION CONCEALS OPPORTUNITIES FOR SUSTAINABILITY IMPROVEMENT

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ABSTRACT

In analyses of action options regarding sustainability, the economic theory of production is often used as a conceptual starting point. We contend that this theory is deficient, even counterproductive. Especially, we argue that effective options exist for sustainability improvement that are not visible in this theory, and thus will not be taken into consideration when comparing alternative options based on it.

We argue that the fundamental problem of the economic theory of production is that it cannot explain the formation of either cost or value in an adequate way. This situation seems to have been caused by the foci and assumptions of the "marginalist turn" of economics, starting from 1870, especially the denial to consider any internal organization of production other than that caused by prices and costs, the assumption of optimal efficiency, and the assumption of ends as given.

The shortcomings of the economic theory of production are demonstrated through a case study on plasterboard (also known as drywall) installation. We show how practices for installation of these products, as advocated in lean construction, would not have been suggested or visible in a "sustainability" analysis based on economic theory.

KEY WORDS

Theory of production, economics, sustainability, lean production, waste, plasterboard, drywall, installation.

INTRODUCTION

In analyses of action options regarding sustainability, the economic theory of production is often used as a conceptual starting point. It is well known that this theory of production has been challenged from the sustainability point of view, especially regarding the omission of links to the biophysical world (Georgescu-Roegen 1970), and improved versions of it have been proposed. However, we contend that in spite of these purported corrections and improvements, serious deficiencies remain (Koskela, in print), such as:

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- The assumption that the internal organization of production does not count
- The assumption that there is no waste
- The assumption that ends are given and will be realized

We argue that because of these deficiencies, several effective options for sustainability improvement are not visible in this theory, and thus will not be taken into consideration when comparing alternative options based on it. This theory impact is visible especially at three levels of analysis:

- General discussions on sustainability policy
- Tools and methods of sustainability in detail building design and construction
- Evaluation of sustainability of whole buildings.

This paper is structured as follows. First, we review the problematic features of the economic theory of production. Then, we describe the impact the theory of production has on practical sustainability analyses. Next, we present an empirical analysis using gypsum plasterboard installation as an example. We end the paper with a discussion of findings, and conclusions.

PROBLEMS OF THEORY OF PRODUCTION

The core of the economic theory of production is the technical law relating inputs to outputs, called "production function," defined as follows (Samuelson and Nordhaus 1985):

> The production function is the technical relationship between the maximum amount of output that can be produced by each and every set of specified inputs (or factors of production). It is defined for a given state of technical knowledge.

The framework of the then-new "scarcity economics", containing the theory of production as an integral part, has been developed and promulgated since 1870s. The key promoter of the scarcity idea was Lionel Robbins, who published the influential "Essay on the Nature and Significance of Economic Science" in 1932. Today, this view is commonly accepted among economists. Unfortunately, this economic theory of production is plagued by invalid and counterproductive assumptions (Koskela, in print). In the following, three of these assumptions are analyzed.

INTERNAL ORGANIZATION OF PRODUCTION

In the afore-mentioned book, Robbins (1935) argues that productive organization is essentially determined by the relationships between costs and prices, and that any internal industrial arrangements can be abstracted away, at least for the purpose of an economic analysis. The problem of doing so is that arguably the output of production is dependent on two sets of factors, first, the technology, but also the theoretical basis and the quality of implementation of production management (which determine the amount of waste), that is, the internal arrangements.

The huge differences in the impacts of production management have been commonly known at least from the 1920s (Anon. 1921). Even within one company, performance differences may be as great as 2:1 (after controlling for other differences in age, technology, etc.) between the best and worst plant (Chew et al. 1990). However, economists have failed to act upon this knowledge—obviously, because the matter of internal industrial arrangement has been paradigmatically excluded from economic consideration. The assumption to be considered next, about the best possible productive efficiency, is closely related to the denial of the influence of internal arrangements: if production is anyway carried out to the best possible efficiency, there cannot be any factors disturbing this admirable state of the affairs.

BEST POSSIBLE PRODUCTIVE EFFICIENCY

The mainstream economic doctrine includes the assumption of optimal productive efficiency of firms. For example, in his book on construction economics, Myers (2004) says:

> In any free market economy businesses will never waste inputs. A business will not use 10 units of capital, 10 units of labour, and 10 units of land when it could produce the same amount of output with only 8 units of capital, 7 units of labour, and 9 units of land.

In reality, just the opposite of Myers' claim prevails: businesses always waste inputs, more or less. As Womack and Jones (1996) state it: "muda is everywhere". Similarly regarding construction, it has been argued that high levels of waste are a normal phenomenon in this industry (Koskela 2000), and that waste is omnipresent in construction supply chains (Arbulu and Tommelein 2002).

Surely, if one assumes that the whole economy is producing with maximal efficiency, waste will not be visible and the reduction of waste cannot be perceived as a worthwhile way of increasing efficiency.

ENDS AS GIVEN

Regarding ends, Robbins (1935) argues:

> Economics, we have seen, is concerned with that aspect of behaviour which arises from the scarcity of means to achieve given ends. It follows that Economics is entirely neutral between ends… Economics is not concerned with ends as such. It assumes that human beings have ends in the sense that they have tendencies to conduct which can be defined and understood, and it asks how their progress towards their objectives is conditioned by the scarcity of means-how the disposal of the scarce means is contingent on these ultimate valuations.

Thus, the assumption is that ends are given and that they are separate from means; but are they? The industrial practice especially in the construction domain reveals that: first, ends (i.e., client requirements) are not immediately clear and stable, but rather implicit and evolving; second, ends and means are intimately interrelated: often ends emerge only when the corresponding means have been developed or the client has been made aware of them. Thus, a conversation between means and ends is needed; and third, most often ends cannot be realized in one pass (decision), but a multilayered ends-means hierarchy is needed. Thus, ends cannot be seen as static, fixed starting points, but they must be seen as moving targets to be managed throughout the production process.

For most products, it would be crucial to distinguish which are the desired functionalities of the output of the system that produces them and whether that output has defects; unfortunately, the production function is silent about these issues. Thus, the production function does not adequately explain how valuable outputs can be realized.

SUMMARY OF THE CRITIQUE OF THE THEORY OF PRODUCTION

We have discussed three shortcomings of the economic theory of production:

- The assumption that the internal organization of production does not count
- The assumption that there is no waste
- The assumption that ends are given and will be realized

In the following, first we show that these assumptions replicate in practical analyses of sustainability analyses, and second we endeavor to falsify, through empirical evidence, all three assumptions.

IMPACT OF THE THEORY OF PRODUCTION ON PRACTICAL SUSTAINABILITY ANALYSES

Economics has had a considerable intellectual influence generally[3] and also on sustainability analysis. We contend that the assumptions underlying the economic theory of production can also be discerned at least on three levels of sustainability analysis.

GENERAL DISCUSSIONS ON SUSTAINABILITY POLICY

Ashford and Caldart (2008) provide a fresh discussion on policy options towards sustainability. They criticize the current strategy agendas for being reactive and, at best, coordinated. They call for sustainable agendas that are integrated, addressing all important social goals simultaneously. According to them, radical or disruptive technological, social, and organizational innovations are needed for achieving the needed improvements of a factor of ten or greater in eco- and energy efficiency and reductions in the production and use of toxic substances.

In the analysis of Ashford and Caldart, the economic theory of production and its assumptions seem to be implicitly accepted. Reduction of waste and increase of output value through improved internal organization of production is not seen as an option. Counterproductive economic theory of production is not listed among the sources of unsustainability, neither is, say, lean production (that visibly rejects the mentioned assumptions), among the solutions towards sustainability.

TOOLS AND METHODS OF SUSTAINABILITY IN BUILDING DESIGN AND CONSTRUCTION

Several tools exist for comparing different design choices from the sustainability point of view, for example LCADesign (Seo et al. 2007, Pearce et al. 2003). Typically,

[3] For example, traditional project and construction management has largely tended to assume ends as given (Koskela and Howell 2002). This has been detrimental as in resulting practice the project realization process inadvertently runs in parallel to the discovery of ends. It is probable that the prior prevalence of this assumption in economics has influenced project and construction management.

they calculate, starting from the geometric form of the building and its components, the amounts of different materials and the related sustainability impacts. While useful for comparing different materials and solutions, these tools turn attention away from the possibility of using materials with different degrees of efficiency, and thereby rely on the assumption in the economic theory of production of fixed input-output relations. Also, as the internal organization of production or ends of production are not conceptually covered in these tools, it is clear that these topics are not seen as actionable variables (similarly to the theory of production in economics).

EVALUATION OF SUSTAINABILITY OF BUILDINGS

The assessment and rating of buildings for sustainability has grown in popularity in recent years. Two major methods are in use: BREEAM and LEED.

BREEAM (The Environmental Assessment Method for Buildings around the World) is a British assessment method for buildings. Credits are given regarding the following environmental impacts: management; health and well-being; energy; transport; water; material and waste; land use and ecology; and pollution. Regarding materials and waste, BREEAM covers materials with a low embodied energy, buildings where part or all of an existing building is being re-used (i.e., refurbishment projects), responsibly sourced materials, and use of recycled materials.

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is an American assessment method. In LEED, points are given for sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation and design process. Under materials and resources, points are given to: storage and collection of recyclables (required); building reuse; construction waste reuse or recycling; reuse of existing materials; recycled content; use of local materials; rapidly renewable materials, and certified wood.

Thus, in neither system is the actual, realized material waste taken into account as a criterion for assessment. This matches with the assumption in the economic theory of production on fixed input-output relations. Also, neither system addresses the realization of such requirements that are not related to sustainability. In turn, this matches with the assumption of given ends and their non-problematic realization.

GYPSUM PLASTERBOARD INSTALLATION: EMPIRICAL ANALYSIS

Next, we use examples from practice to illustrate our point: trade-offs have to be made between production, transportation, materials use, and ultimate quality. How these trade-offs are made has an impact on sustainability metrics.

Consider construction of a wall system using gypsum plasterboard (also known as drywall panels). This technology was commercialized in the early 1900s, replacing hands-on application of wet plaster on wooden slats. Panels of standardized sizes get manufactured off-site and are shipped to site for installation and finishing, reducing and simplifying the labor effort required on site to achieve smooth wall surfaces.

Plasterboard panels with dimensions 4 feet by 8 feet (4x8) and ½ inch thick [122 cm by 244 cm by 1,25 cm thick] are readily available in the United States; they are the standard in the retail market (plasterboards of roughly similar dimensions are common also in the UK). They weigh around 50 pounds, the limit of what a single person can carry safely. Panels are finished with tapered ends along their length.

Cutting a panel leaves a butt seam that requires greater care to finish than a seam of tapered ends would. In addition to dimension and weight characteristics, panels have other characteristics, many of which are not so readily discernable with the naked eye. For example, plasterboard has a grain, paralleling the long tapered edge of the sheet. The panel has more strength with the grain than across, so running the long edge of the panel perpendicular to the framing whenever possible will result in stronger construction (from http://www.buyezrip.com/Drywall-Facts.htm visited 4/2/09). To make it easy for installers to see whether or not a piece of plasterboard is water resistant (as needed in places with high humidity, e.g., bathrooms), manufacturers make regular plasterboard panels white vs. water-resistant panels green.

In keeping with the lean practice 'gemba gembuchi,' loosely translated from Japanese to 'go to the work face and observe first-hand what really is happening there,' we next show how plasterboard gets installed. The trade literature offers how-to tips (e.g., Waddell 1993, Ferguson 2004). Figure 1 shows panels being secured to wall studs, and stiffening of an otherwise unsupported plasterboard joint. Figure 2 shows a panel cut around an opening in order to guarantee a smooth finish at the corners. Figure 3 shows a worker hanging plasterboard to wall framing using screws, then filling every seam between panels with joint compound, covering them with tape, and smoothing the surface further with compound. When all that is done, the worker will sand the surface to smooth the concealed joint, and ready it for final surface treatment such as painting. With this shared understanding of plasterboard installation, we next revisit the assumptions made in the economic theory of production, and show how they overlook salient features of this process.

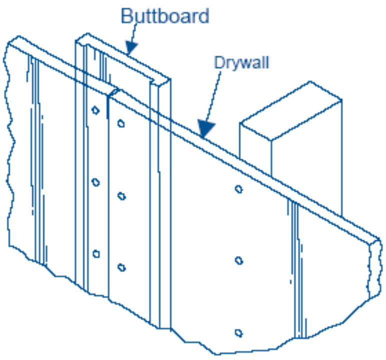

Figure 1: Backing for Otherwise Unsupported Plasterboard Joint (Advertisement for Buttboard™ From www.trim-tex.com)

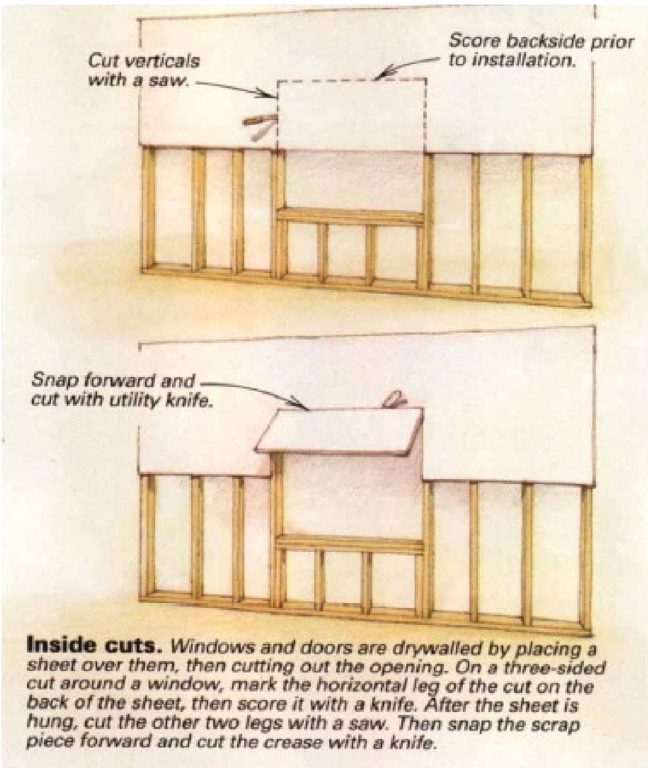

Figure 2: Plasterboard Placement Around Wall Opening ("Inside Cuts" From Wardell 1993 p. 42)

Figure 3: Plasterboard Fastening and Joint Finishing (Ferguson 2004)

INTERNAL ORGANIZATION OF PRODUCTION COUNTS

Panels are hung and attached to wall- or ceiling studs, so if a building is not entirely modular (they practically never are), the dimensions of the panel will not exactly fit the surface to be covered. Accordingly, workers must organize their production process, e.g., determine how to stage and lay out panels, what panels to cut and where, or if/when to use stiffeners should panels end in-between studs. They can use cut pieces to cover smaller areas, or piece them together on larger ones. They also can mix and match panels of different sizes to minimize other installation effort and possibly minimize waste.

A drive for higher worker productivity (lowering of process waste) tends to promote use of larger panels (e.g., 10 feet or 12 feet long [305 cm or 366 cm long]) but also outputs more plasterboard-remnant waste (product waste). Generally-speaking, more pieces take more time to install and demand more seams to finish. Using larger panels, the covered area will have fewer seams, judicious cutting can sometimes result in less waste than smaller panels would have caused, but larger panels will require 2 people or special means to handle.

The relationship between process waste and product waste does not depend on the plasterboard trade alone. On projects, worker productivity for plasterboard installation and finishing may have to be balanced with productivity of other trades, such as mechanical ductwork installation (e.g., Mikati et al. (2007) describe coordination around ‘priority walls’), in order for the project to be delivered most effectively. Indeed, Ohno (1988) suggested there are 7 kinds of waste; these wastes are interrelated with one another and must be managed holistically.

In rules used for estimating and procurement, broad assumptions are made with regards to the internal organization of production, with safety factors masking opportunities for improvement.

WASTE ABOUNDS

The Whole Building Design Guide (http://www.wbdg.org/design/greenspec_ msl .php?s=092900) includes a 'green' specification for drywall that reads:

PART 3 - EXECUTION 3.X SITE ENVIRONMENTAL PROCEDURES
A. …
B. Waste Management: As specified in Section 01 74 19 (01351) - Construction Waste Management and as follows:
   1. Select panel sizes and layout panels to minimize waste; reuse cutoffs to the greatest extent possible.

Such a 'green' specification encourages measuring waste that is relatively easy to measure, but doing so is too myopic because it promotes local optimization: by overly focusing on materials waste, one may end up wasting other resources such as labor time. Sustainability metrics must address the question: What is the appropriate amount of extra time to spend (labor cost to incur) in order to save materials?

Continuing with the plasterboard example, waste stems from:

- Matching standard panel dimensions to room dimensions and openings (doors, windows, heating duct penetrations, etc.): this waste (calculated by dividing the area of the surface to be covered by the area per panel, and then rounding up to the next integer to yield the number of panels needed) can be on the order of 2% to 15% of panels delivered, depending on work requirements, even without further accounting for cutting to line-up panel edges with wall studs.
- Workmanship in handling and cutting panels to their desired shape (breaking panels during handling, mistakes in measurement, etc.)
- Moisture damage resulting from inappropriate storage or application of plasterboard.

Such wastes and others (such as plasterboard supply and handling waste as described by Blomqvist et al. 2009) can add up significantly industry-wide. For example, the State of California reports waste from use of drywall (plasterboard) in new construction to rise to over 200,000 tons in California per year (Wallboard (Drywall) Recycling).

ENDS ARE ILL-SPECIFIED

The end product of plasterboard installation is a wall, but not all walls are of the same quality. There are differences in understanding of what quality level is expected of the outcome. The desired level of quality tends to not be specified in design drawings and specifications, and it is all too often implicitly assumed that the contractor will use the 'best' means and methods as though there were no cost implications associated with that. Punch-list negotiations and disappointment should then not come as a surprise.

Continuing with the plasterboard example, ends can be ill-specified in the following ways: we referred to plasterboard having a grain, so that panels running the long edge of the panel perpendicular to the framing will result in stronger construction, but panel layout is the worker's choice. Figure 2 showed details on corners, which, if realized alternatively using plasterboard pieces joining at the corner would result in a joint more likely to crack in the lifetime of the facility. The use of stiffeners to support cantilevering panels may leave a joint that could be harder to finish than one against a stud and more likely to move and thus crack later. Finally, extra seams resulting from an effort to minimize scrap plasterboard, means more finishing work (more filler, tape, plus effort to do it) and potentially lower quality of the finished look.

DISCUSSION

Many if not all of the production issues mentioned here do not show up in sustainability analyses. While we used plasterboard to illustrate by means of examples how economic theory fails to see factors that matter in lean thinking, our reasoning applies equally to many other production settings in the construction domain as well as in other domains. We contend that for the promotion of sustainability, it is important to address waste, the internal organization of production, and the value achieved, all three in combination. In doing so, lean can offer a significant means to contribute to sustainability.

CONCLUSIONS

The fundamental problem of the economic theory of production is that it cannot explain the formation of either cost or value in an adequate way. This situation is caused by the denial to consider any internal organization of production other than that caused by prices and costs, the assumption of optimal efficiency, and the assumption of ends as given. The shortcomings of the economic theory of production are demonstrated through a case study on plasterboard (drywall) installation. We show how practices for installation of these products, as advocated in lean construction, would not have been suggested or visible in a sustainability analysis based on economic theory.

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REFERENCES

Anon. (1921). Report on Elimination of Waste in Industry. *Mechanical Engineering*, September, pp. 579-583.

Arbulu, R.J. and Tommelein, I.D. (2002). "Value Stream Analysis of Construction Supply Chains: Case Study on Pipe Supports used in Power Plants." *Proceedings IGLC-10*, August 2002, Gramado, Brazil.

Ashford, N.A. and Caldart, C.C. (2008*). Environmental Law, Policy and Economics: Reclaiming the Environmental Agenda.* MIT Press.

Blomqvist, M., Camitz, M., and Mattson, K. (2009). *Improvement of Material Handling at Construction Sites.* Master of Science Thesis 2009:004, Department of Technology Management and Economics, Division of Logistics and Transportation, Chalmers Univ. of Tech., Göteborg, Sweden.

BREEAM. http://www.breeam.org/index.jsp, accessed April 17, 2009.

Chew, W., Bresnahan, B., Timothy F., and Clark, K.B. (1990). “Measurement, Coordination and Learning in a Multiplant Environment.” pp. 129-162 In: Kaplan, Robert S. (ed.)(1990). *Measures for Manufacturing Excellence*. Harvard Business School Press, Boston.

Ferguson, M. (2002). *Drywall: Professional Techniques for Great Results.* The Taunton Press.

Ferguson, M. (2004). “Invisible Drywall Seams.” *Fine Homebuilding*, June/July, pp. 76-81.

Ferguson, M. (2009). www.thatdrywallguy.com visited 4/5/2009.

Georgescu-Roegen, N. (1970). The Economics of Production. *The American Economic Review*, Vol. 60, No. 2, pp. 1-9.

Koskela, L. (in print) “On the theory of production in economics and production management.” To appear in de Valence, G. (in print) *Modern Construction Economics: New Developments in Theory.* Francis & Taylor.

Koskela, L. and Howell, G. (2002). “The underlying theory of project management is obsolete.” *Proceedings of PMI Research Conference 2002*. Slevin, D., Cleland, D., and Pinto, J. (eds.). Project Management Institute (PMI), pp. 293-302.

Mikati, S., Roller, T., Tommelein, I.D., and Khanzode, A. (2007). "Priority Conversations: A Case Study On Priority Walls." in Pasquire, C.L. and Tzortzopoulos, P. (eds.)(2007). *Proc. 15th Annual Conf. of the International Group for Lean Construction* (IGLC 15), 18-20 July 2007, East Lansing, MI.

Myers, D. (2004). *Construction economics: A new approach*. Spon Press, London.

Pearce, A.R., Hastak, M., and. Vanegas, J.A. (1995). “A Decision Support System for Construction Materials Selection using Sustainability as a Criterion,” *Proceedings of the NCSBCS Conference on Building Codes and Standards*, Albuquerque, NM, November 1-4.

Robbins, L. (1935). *An Essay on the Nature and Significance of Economic Science*. 2nd ed. Macmillan, London.

Samuelson, P.A. and Nordhaus, W.D. (1985). *Economics*. Twelfth Edition. McGraw-Hill Book Company, New York.

Seo, S., Tucker S.N., and Ambrose, M.D. (2007). “Selection of sustainable building material using LCADesign tool.” In: *International Conference on Sustainable Building Asia* - SB07 Seoul, 6. Seoul, Korea, June 27.

Wallboard (Drywall) Recycling. http://www.ciwmb.ca.gov/conDemo/Wallboard/, visited 5/5/2009.

Wardell, C. (1993). “Installing Drywall – How to keep the sheets flat and the seams to a minimum.” *Fine Homebuilding*, No. 81, April/May, 38-43.

Womack, J.P. and Jones, D.T. (1996). *Lean Thinking*. Simon & Schuster.