On the free stream velocity sampling in AL Models: review and assessment with respect to wake description

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Objective and Motivation

Objective: Get the highest possible reliability from the ***Actuator Line Model*** by assessing its dependence on projection function, velocity sampling and operating conditions.

Motivation: I am part of a group that focuses on ***wind farm control***.
Being able to rely on ***high fidelity models*** results is fundamental if we want to correctly take into account ***wake interactio***n for developing new techniques.

Research Questions and Methodology

In starting this work our **research questions** were the following:

1. Can we reach mesh *and* kernel independence?
2. What is the best velocity sampling method?
3. Does the reached degree of accuracy vary with the operating conditions?

Methodology

Numerical simulations performed with **SOWFA** and the **POLIMI-AL**.

Experimental results were obtained during the **UNAFLOW** project.

INTRODUCTION

- The Actuator Line Model;
- Critical Aspects of the Model;
- AL Time Line;

1 - FILTERED ACTUATOR LINE IN SOWFA

- Filtered lifting line theory;
- Validation;

2 - VELOCITY SAMPLING METHODS

- Free stream velocity sampling;
- Data and Setup;
- Results;

3 - OPERATING CONDITIONS

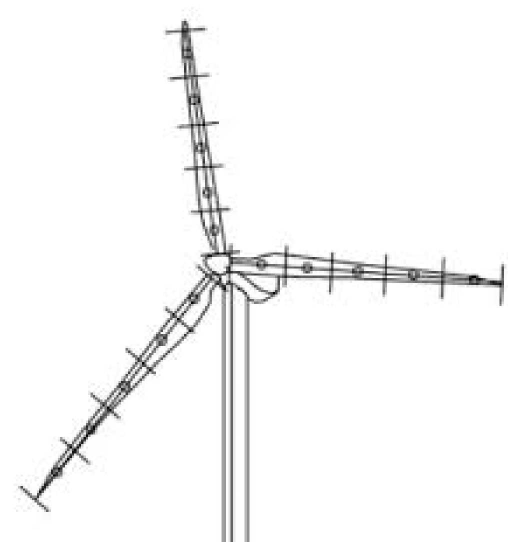
- Results;
- Conclusions;
- Future Works.

INTRODUCTION

Critical Aspects of the Model

When using AL models there are two key aspects:

- The **free-stream velocity** evaluation;
- The **regularization kernel**;



AL TimeLine

AL Introduction
Sørensen and Shen 2002

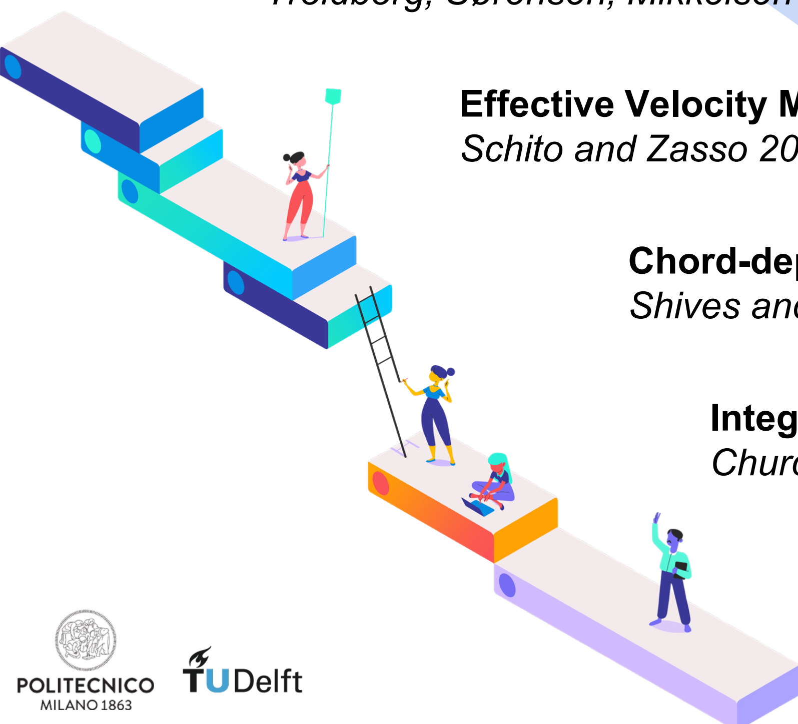
Definition of Guidelines
Troldborg, Sørensen, Mikkelsen 2009

Effective Velocity Model
Schito and Zasso 2014

Chord-dependent optimal ε
Shives and Crawford et al 2012

Integral velocity sampling + non-isotropic gaussian projection
Churchfield et al 2017

Filtered AL
Martinez-Tossaz, Churchfield, Meneveau 2019



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FILTERED ACTUATOR LINE IN SOWFA

Filtered Lifting Line Theory

Objective: To allow the representation of the effects of finite span wings and tip vortices when using Gaussian body forces with a kernel size larger than the optimal value.

Originally tested in LES of flow over fixed wings.

We implemented it in SOWFA.

Validation: Setup

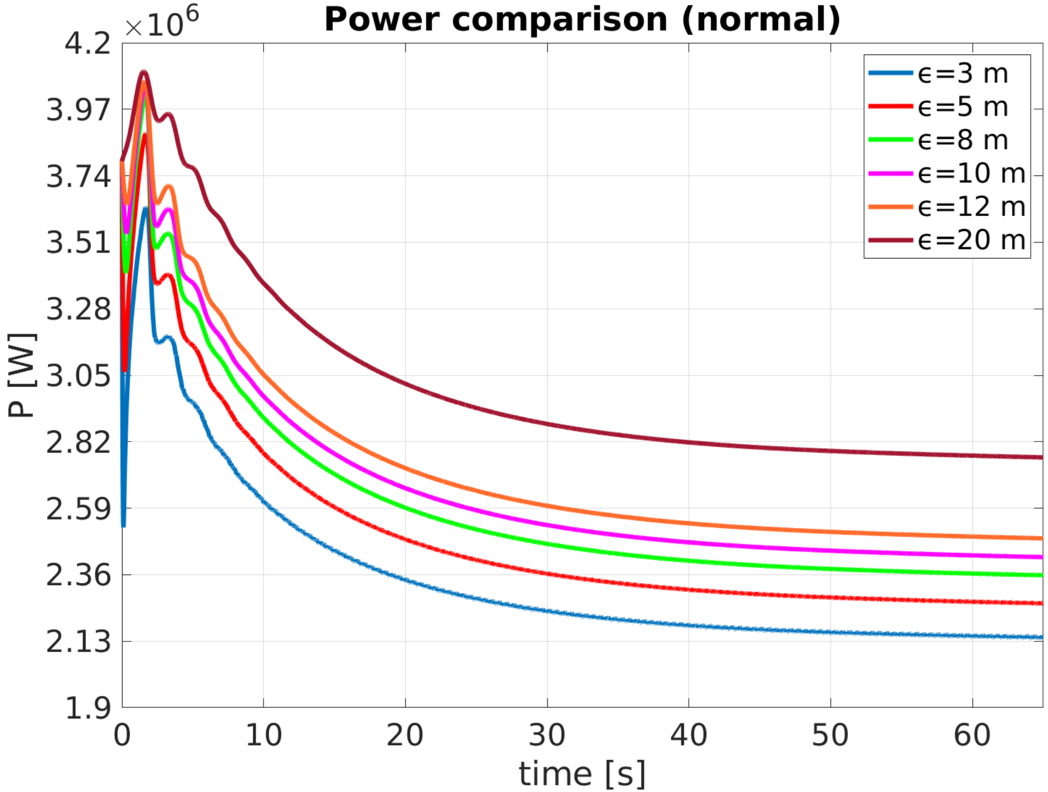
Δ	χ	Average Chord	ϵ_{opt}
1.5 m	42	3.42 m	0.855

Δ is the cell dimension in the rotor area, χ is the number of cells on the radius.

We performed simulations with 6 different values of ε with and without the sub-filter scale correction.

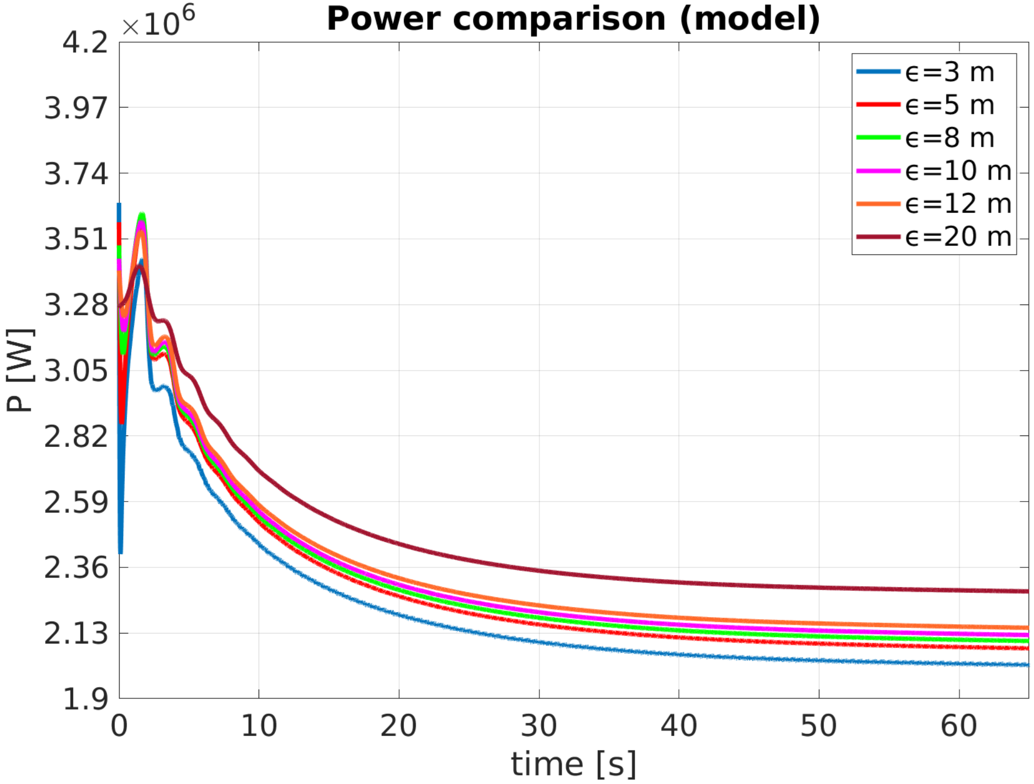
ϵ [m]	ϵ/Δ	ϵ/chord
3	2	0.88
5	3.33	1.46
8	5.33	2.34
10	6.67	2.92
12	8	3.5
20	13.33	5.85

Validation: Results



ϵ [m]	P [MW]	Δ error %
3	2.16	-
5	2.28	5.55%
8	2.38	10.11%
10	2.44	13.03%
12	2.51	16.05%
20	2.79	29.01%

Validation: Results



ϵ [m]	$P_{filtered}[MW]$	Δ error %
3	2.03	-
5	2.09	2.89%
8	2.12	4.14%
10	2.14	5.15%
12	2.16	6.38%
20	2.28	12.56%

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VELOCITY SAMPLING METHODS

Sampling Methods

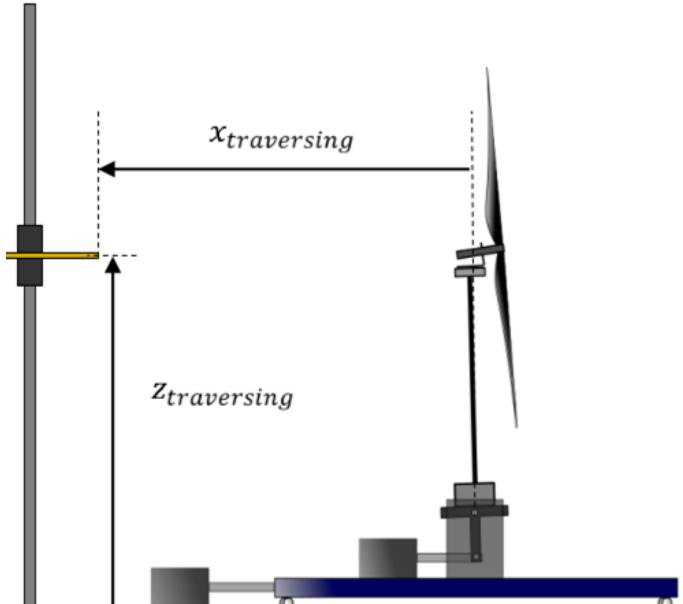
The tested sampling methods were:

- **Linear**: uses linear interpolation from the cell where the actuator point lies and the from neighboring cells;
- **Integral**: computes the actuator point velocity as the integral of the local velocity and the force distribution function following Spalart's formulation;
- **EVM:** computes the actuator point velocity as an average along a sampling line positioned upstream of the rotor then corrects the angle of attack.

Experimental Data

The turbine is a 1:75 model of the DTU 10 MW reference turbine (D=2.38 m).

Data Considered:
Cp and Ct curves.
Cross-wind measurement taken with the set-up in figure.



Case Setup

Boundary Conditions

Patch	U	p	k	nuSgs
west	fixedValue $(U_\infty, 0, 0)$	zeroGradient	fixedValue 0	fixedValue 0
east	inletOutlet	fixedValue 0	zeroGradient	zeroGradient
lower	slip	zeroGradient	zeroGradient	zeroGradient
upper	slip	zeroGradient	zeroGradient	zeroGradient
north	slip	zeroGradient	zeroGradient	zeroGradient
south	slip	zeroGradient	zeroGradient	zeroGradient

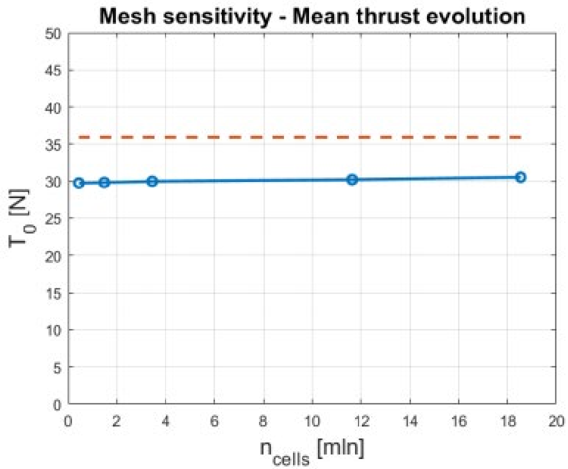
Time step size

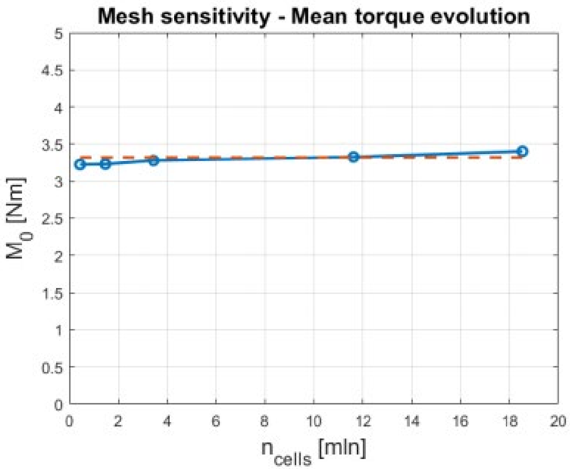
In AL-LES simulations, in addition to the prescription of keeping the Courant number below 0.5, there is a phisical constraint on the time step: we should prevent the tip of the blade line from crossing more than one cell per time step.

Case Setup

Mesh sensitivity

The chosen convergence parameters are the integral thrust and torque values predicted for the rated conditions.





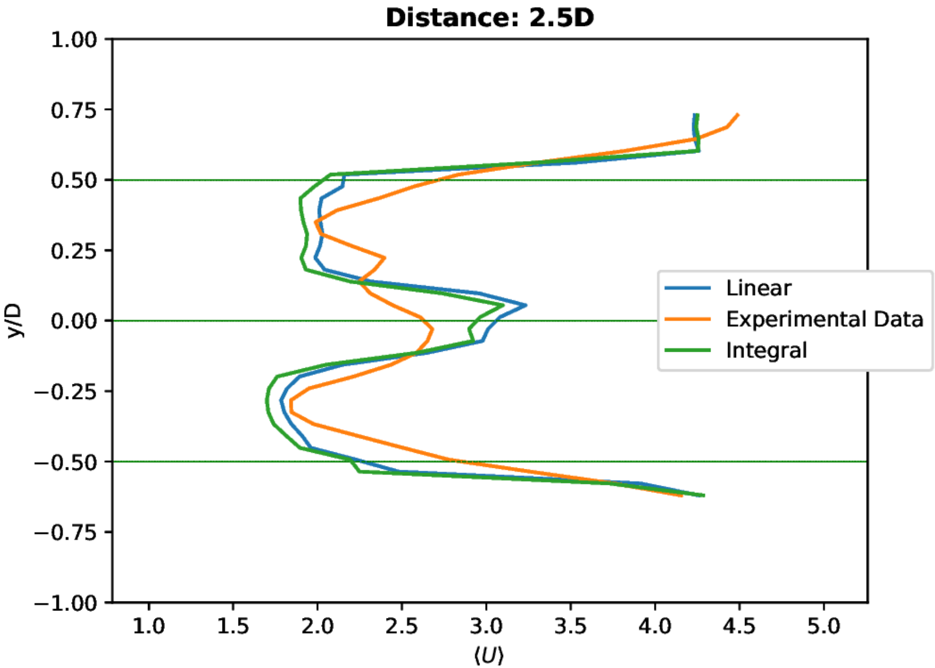
Mancini, Simone, et al. "Characterization of the unsteady aerodynamic response of a floating offshore wind turbine to surge motion." *Wind Energy Science* 5.4 (2020): 1713-1730.

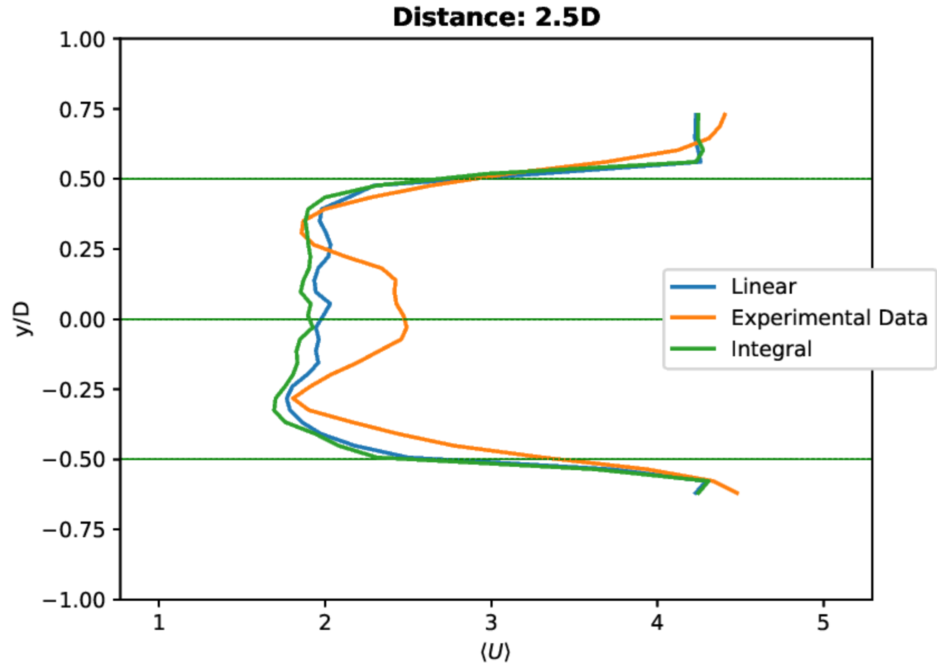
Velocity Sampling Comparison: Performances

Wind speed	Rotor speed	TSR	Pitch angle
3.88 m/s	241 rpm	7.67	0

	Thrust [N]	Δ error %	Torque [Nm]	Δ error %
Experiment	**37.09**	-	**3.05**	-
Linear	30	-19%	2.9	-4.9%
Integral	31.4	-15%	3.12	2.3%
EVM_{polimi}	34.23	-8 %	2.99	-2 %
EVM_{sowfa}	27.57	-25.7 %	2.65	-13 %

Velocity Sampling Comparison: Wake Description

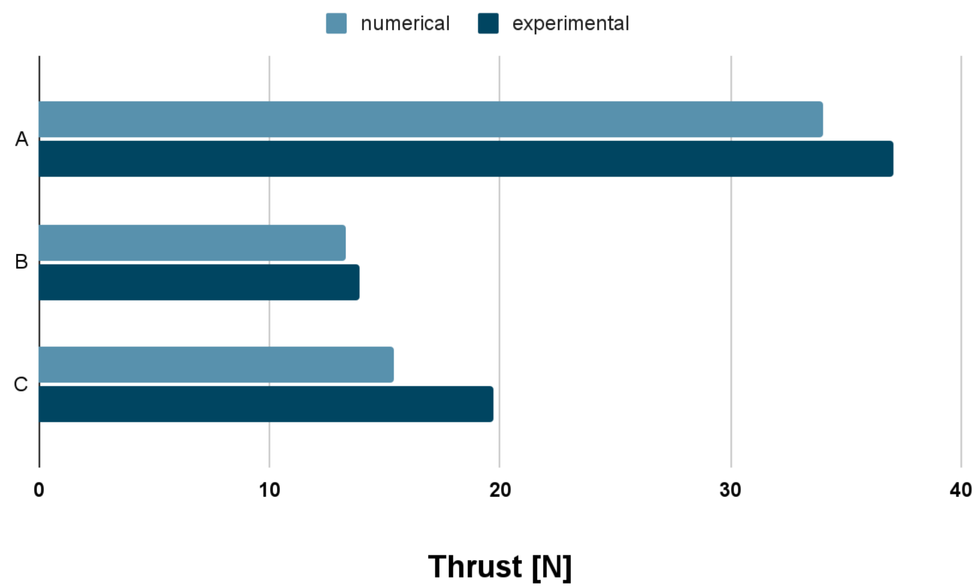




DIFFERENT OPERATING CONDITIONS

Tested conditions and results

Condition	Wind speed	Rotor speed	TSR	Pitch angle
A	3.88 m/s	241 rpm	7.67	0
B	2.5 m/s	150 rpm	7.5	0
C	6 m/s	265 rpm	5.5	12.5°



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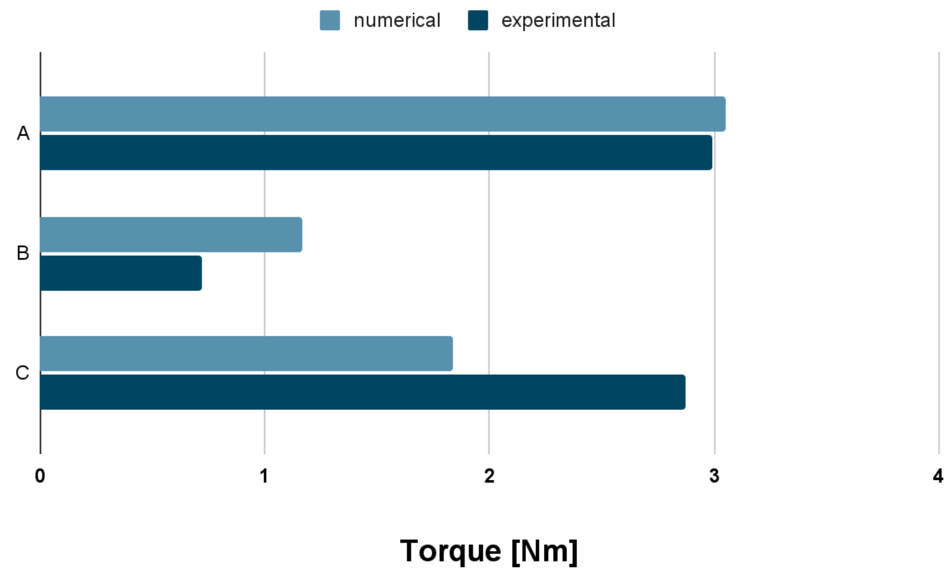

Conclusions

- We implemented in SOWFA a filter that **significantly reduces** the effects of ε on AL simulations;

- We tested the most promising velocity sampling methods available and found that the most accurate results in terms of **performances prediction** are found with the **EVM**;

- We observed that the optimal actuator line parameters are **dependent on operating conditions** and not merely geometric characteristics.

Future Works

- Investigate further the filtered actuator line;
- Fix the EVM implementation in SOWFA;
- Repeat and extend the analysis.