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Up-scaling innovations in an interdependent, costly, and regulatory-uncertain environment: the case of the mobility ecosystem

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María Teresa AGUILAR ROJAS
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Composition du jury :

Jean-Michel DALLE Professeur, Sorbonne Université	*Président du Jury*
Carine STAROPOLI Maître de conférences, Université Paris 1 Panthéon-Sorbonne, PSE	*Rapporteuse*
Bérangère Lauren SZOSTAK Professeure, Université Paris-Saclay, UVSQY	*Rapporteuse*
Julien JOURDAN Professeur Associé, HEC Paris	*Examinateur*
Yannick PEREZ Professeur, Université Paris-Saclay, CentraleSupélec	*Examinateur*
Éric, BROUSSEAU Professeur, Université Paris-Dauphine - PSL	*Directeur de thèse*

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RÉSUMÉ

La mobilité connaît actuellement une transformation importante due à trois facteurs principaux. Premièrement, les systèmes de propulsion électriques et hydrogènes remplacent progressivement les moteurs à énergie fossile des véhicules. Deuxièmement, la révolution des données et les nouvelles technologies de pointe permettent aux véhicules de communiquer avec un grand nombre d'autres entités connectées (par exemple, les infrastructures, les autres véhicules, les piétons, etc.). Troisièmement, le degré d'intervention humaine dans le processus de conduite devenant non essentiel, cela conduit au remplacement des voitures à conduite humaine par des véhicules dits « autonomes ».

Au cours de la dernière décennie, les technologies des véhicules électriques et autonomes se sont abondamment développées car elles offrent la possibilité de créer de la valeur, tout en résolvant certains des plus grands problèmes de mobilité dans le monde. Les véhicules électriques (VE) réduisent la pollution atmosphérique locale, le bruit du trafic et pourraient éventuellement réduire les émissions de Gaz à effet de serre lorsqu'ils sont couplés à un mix énergétique à faible teneur en carbone (Hawkins, Singh, Majeau-Bettez, & Strømman, 2013). Les véhicules autonomes (VA) réinventent quant à eux la façon dont les individus travaillent et passent leur temps libre, ont le potentiel de réduire les accidents de la route, d'accroître l'accès aux populations vulnérables et d'augmenter la capacité de mobilité des populations résidant dans des zones peu desservies par les transports publics (J. Anderson et al., 2016). En outre, on peut s'attendre à observer des synergies entre ces deux innovations que sont les VE et les VA. Même si les VA ne doivent pas nécessairement être électriques et vice versa, les véhicules électriques pourraient stimuler la mobilité autonome. Les véhicules électriques sont plus sûrs, plus durables et nécessitent moins d'entretien. Parallèlement, les véhicules autonomes stimulent la mobilité électrique, en augmentant les diverses applications et services offerts et leur efficacité énergétique et temporelle, ce qui les rend plus durables. Si elles sont intégrées, on peut s'attendre à ce que ces innovations changent non seulement notre façon de nous déplacer, de travailler et les services que nous consommons, mais aussi à ce qu'elles redessinent les villes dans lesquelles nous vivons, comme l'ont déjà fait les voitures avant elles.

Cependant, malgré les avantages de la mobilité électrique et autonome, une transition généralisée vers ces deux innovations n'a pas encore eu lieu. Par exemple, depuis que les VE sont devenus un marché naissant et prometteur A partir des années 2010, leur adoption a été lente. La part de marché mondiale des VE ne représentait ainsi que 4,6 % en 2020, et le nombre de véhicules électriques personnels représentait moins de 1 % de toutes les voitures en circulation dans le monde (IEA, 2021a). En ce qui concerne les VA, leur adoption et acceptation ont également été lentes. Alors qu'en 2010, les perspectives étaient optimistes pour le développement des technologies des véhicules autonomes, à la fin de la décennie, la vision est moins utopique. Jusqu'à présent, les VA sont encore au stade de test et de développement, et aucune entreprise n'en est encore parvenue au stade de leur production et commercialisation à grande échelle. En effet, les plans de commercialisation de masse de la plupart des acteurs du secteur des VA ont été reportés à des dates ultérieures.

Le retard pris dans la transposition à grande échelle de ces innovations peut être attribué en partie à leur complexité technique. Dans le cas des VE, l'autonomie[1], la densité énergétique des batteries[2] ou encore leur temps de charge présentent encore à ce jour de nombreuses inconnues techniques. Pour les VA, le développement d'une technologie garantissant que le véhicule est capable de percevoir son environnement mieux que les meilleurs conducteurs humains est également complexe. La vision par ordinateur et les cartes détaillées garantissant la sécurité de ces véhicules restent en effet encore un défi majeur. Par exemple, la capacité de détecter et de classer avec précision des objets dans des situations inhabituelles est une tâche difficile qui nécessite un grand nombre de tests et de données que le véhicule doit maîtriser. Enfin, les VA doivent communiquer en temps réel. Choisir la bonne technologie de communication pour que le véhicule puisse traiter de grandes quantités de données très rapidement et donner une réponse immédiate aux récepteurs constitue un autre de ces défis. Enfin, la sous-estimation antérieure des difficultés technologiques, ayant conduit à des accidents mortels impliquant des systèmes autonomes, a contribué à une baisse de l'optimisme quant à ces technologies. Néanmoins, certaines avancées technologiques ont permis maintenir cet optimisme. Par exemple, la densité des

[1]L'autonomie est la distance qu'un VE peut parcourir avec l'énergie stockée dans sa batterie.

[2]La densité énergétique de la batterie est la quantité d'énergie transportée par une batterie de taille ou de poids donnés.

batteries de certaines versions 2018-2019 de VE les plus courants est de 20 à 100 % supérieure à celle de leurs équivalents de 2011-2012 (IEA, 2020). Grâce aux progrès de la recharge rapide, les temps de charge ont aussi été grandement diminués[3], permettant à certains VE d'atteindre une charge de 80 % en 15 minutes, en moyenne (Tritium, 2020). Les avancées technologiques sur les VA ont également été importantes. On pourra citer l'exemple de la plateforme DRIVE PX AI[4] de Nvidia, qui est 10 fois supérieure à sa version précédente, DRIVE PX 2 (Pal, 2018).

La littérature sur l'innovation reconnaît depuis longtemps que la performance des technologies est importante mais pas suffisante pour une diffusion ou une mise à l'échelle réussie d'une innovation (Montalvo, 2008). Les défis socio-institutionnels et ceux liés aux infrastructures sont à ce titre cruciaux pour la transition vers les nouvelles technologies. Trois principaux obstacles socio-institutionnels peuvent retarder la transition vers les nouvelles technologies : les intérêts différents et parfois contradictoires des parties prenantes dans un écosystème, les retards d'implémentation des infrastructures et enfin l'incertitude réglementaire.

Tout d'abord, la transformation de la mobilité n'est pas seulement le terrain de jeu des constructeurs et des fournisseurs d'automobiles, mais aussi celui d'acteurs nouveaux et émergents issus d'autres secteurs. Pour exemple, le développement des VA n'est pas uniquement piloté par les constructeurs automobiles (par exemple Renault-Nissan, Tesla et BMW), mais aussi par les fournisseurs de matériel (par exemple Delphi, Intel et Nvidia), les fabricants de logiciels (par exemple Nvidia), les fournisseurs de ces logiciels (par exemple, Apple, Microsoft et Waymo), mais encore les entreprises de covoiturage (Didi Chuxing, Uber et Lyft). Les parties prenantes impliquées sont donc de plus en plus interdépendantes (Adner, 2017; Iansiti & Levien, 2004). Chacun des acteurs fait appel à ses capacités pour développer différents composants qui forment le produit final, et choisit de coopérer dans certains composants, en créant des alliances stratégiques ou en engageant des investissements stratégiques, au lieu de développer le produit entier par eux-mêmes. Certains de ces composants, appelés "composants goulots", peuvent limiter ou entraver le développement du produit final. Par exemple, la capacité d'identifier et de

[3]Les temps de charge peuvent diminuer à un rythme de 250-500 kW pour les voitures en cours de déploiement ou annoncées, une avancée par rapport à la capacité de 50 à 120 kW de la plupart des modèles actuels de voitures électriques.

[4]Nvidia Drive est une plateforme informatique de Nvidia, destinée à fournir des fonctionnalités de voiture autonome et d'aide à la conduite grâce à l'apprentissage profond.

classer les objets comme l'œil humain est une composante qui pourrait à elle seule compromettre le fonctionnement global des VA. Face à un composant goulot, différents acteurs peuvent alors être amenés à coopérer pour poursuivre le développement du produit focal. Or, ces collaborations ne va pas toujours de soi, car les acteurs de l'écosystème de la mobilité sont motivés par des incitations différentes et parfois contradictoires. Par exemple, pour faire avancer le développement d'un composant goulot, les grandes entreprises qui manquent d'expertise spécialisée peuvent investir dans des start-ups spécialisées dans ce composant pour aider à résoudre le goulot d'étranglement. Mais ces start-ups courent le risque que les entreprises avec lesquelles elles coopèrent abusent de leur position sur le marché pour entraver les innovations ou ralentir leur développement parce que cela correspond à leur intérêt. L'équilibre entre coopération et concurrence devient crucial dans ce contexte. Dans l'écosystème de la mobilité, les innovations reposent sur l'utilisation et la coordination de ressources rares, telles que le sol. Ces innovations diffèrent donc des innovations sur d'autres marchés, par exemple les marchés numériques. En raison de la dépendance à l'égard des terres, les acteurs publics jouent un rôle dans les écosystèmes de mobilité. Dans ce contexte, la coordination des incitations entre les acteurs, publics et privés, présente donc une difficulté supplémentaire.

Deuxièmement, les innovations nécessitent des changements d'infrastructure considérables qui sont coûteux à mettre en œuvre. Les VE nécessitent par exemple l'installation de nombreuses bornes de recharge le long des routes. De même, les VA nécessitent des routes adaptées aux caméras et aux capteurs pour exploiter les réseaux de communication entre véhicules et infrastructures (V2I), ainsi que les réseaux 5G pour éviter les décalages de communication entre les véhicules et leur environnement. Dans le cas où ces technologies doivent être couplées avec le réseau de transport public d'une municipalité, il faut également prévoir les changements dans ce réseau de transport. Toutes ces modifications d'infrastructures représentent un coût élevé pour les acteurs du marché et cela signifie qu'ils doivent fonctionner avec des coûts irrécupérables[5] pendant une longue période. Si les coûts irrécupérables posent un problème aux acteurs du marché, ces technologies pourraient bénéficier d'économies d'échelle[6], si elles

[5] Un coût irrécupérable est un coût qui a déjà été engagé et qui ne peut être récupéré.

[6] Les entreprises peuvent réaliser des économies d'échelle en augmentant la production et en réduisant les coûts. Cela se produit parce queles coûts sont répartis sur un plus grand nombre de produits. Les coûts peuvent être à la

étaient répandues. Cependant, jusqu'à présent, ces technologies ne sont pas répandues mais à un stade relativement précoce. Aux premiers stades de l'innovation, il y a une incertitude concernant la demande effective. Par conséquent, les acteurs du marché et leurs investisseurs hésitent à engager des ressources tant qu'il n'existe pas de marché bien établi. C'est le cas pour les VE, où les utilisateurs potentiels hésitent à acheter de tels véhicules tant qu'il n'y a pas suffisamment de stations de recharge, et où les acteurs du marché hésitent réciproquement à installer davantage de stations de recharge tant qu'il n'y a pas suffisamment de VE à desservir sur les routes. Alors, qu'est-ce qui doit venir en premier : les véhicules ou la station de recharge ? Cette question – qui n'est pas sans rappeler le dilemme de l'œuf et de la poule –reste l'un des principaux obstacles à la diffusion des VE à grande échelle.

Le troisième et dernier obstacle est que les réglementations ne sont pas encore à jour par rapport aux innovations. Le processus réglementaire est généralement lent, étant donné les cycles de propositions, de demandes de commentaires, d'examens et de lobbying qui précèdent l'élaboration des règles. En particulier avec les nouvelles technologies qui sont complexes et évoluent rapidement, il y a une grande incertitude sur le résultat, et prescrire des règles qui peuvent rester pertinentes est un défi (J. Anderson et al., 2016). La multiplicité des parties prenantes ajoute également à la complexité du processus réglementaire, car elles peuvent ici aussi avoir des intérêts divergents. Certains acteurs peuvent être réfractaires à la réglementation, car ils affirment que les technologies n'évoluent pas nécessairement dans la lignée de la régulation et que la réglementation peut entraver le développement technologique. Cependant, les réglementations peuvent également permettre aux fabricants de savoir clairement comment et quand la technologie fonctionnera et fournir des signaux aux personnes qui interagissent avec la technologie en question. Par exemple, les règlements sur la sécurité des véhicules permettraient aux fabricants de logiciels de conduite autonome de programmer leurs voitures pour qu'elles agissent dans les limites suggérées en termes de vitesse du véhicule. De même, les réglementations sont également importantes pour garantir la cybersécurité, la protection des données et l'accès à celles-ci. Elles doivent assurer un équilibre entre le partage des données des véhicules qui permet une concurrence loyale dans la fourniture de services, tout en garantissant le respect

fois fixes et variables.

de la législation sur la protection des données personnelles. Ils pourraient également déterminer qui détient la responsabilité de quelles actions en cas d'accident. Pour comprendre les détails des technologies, les régulateurs ont besoin de la contribution des entreprises du marché. Les régulateurs fournissent des instruments tels que des consultations pour donner un retour d'information sur l'élaboration des règles. Cependant, les entreprises ont naturellement des motivations différentes, ce qui affecte la manière dont elles communiquent avec les régulateurs.

Les acteurs qui participent à l'écosystème de la mobilité sont conscients de ces défis et ont mis en place différentes stratégies pour y répondre. Tout au long de cette thèse, j'explore les stratégies utilisées par les acteurs afin de surmonter les défis socio-institutionnels de la transition vers un secteur moderne de la mobilité. Ainsi, je souhaite répondre à la question suivante : *Comment les acteurs participant au développement des véhicules électriques et autonomes façonnent-ils leurs stratégies afin de développer les innovations dans un marché interdépendant, dépendant des infrastructures et incertain du point de vue réglementaire ?* J'explore cette question sous trois angles différents, chacun correspondant à un chapitre de cette thèse, comme illustré à la figure 1. Chacun des chapitres se concentre sur l'un des trois barrières de l'initiative susmentionnée qui évitent la mise à l'échelle : le décalage des incitations des parties prenantes dans un environnement coopératif, les retards d'infrastructure et l'incertitude réglementaire.

Le premier chapitre, l'introduction, fournit le contexte des trois perspectives : un aperçu des technologies des véhicules électriques et autonomes. Il commence par souligner le rôle des transports dans notre économie. Ensuite, il donne un aperçu de l'histoire et de l'état de l'art des technologies, afin de fournir une image générale de leur évolution et des enjeux actuels. Ensuite, il explore le potentiel de création de valeur des VE et des VA. Enfin, il évoque les trois obstacles à la mise à l'échelle mentionnés ci-dessus (c'est-à-dire l'inadéquation des incitations des parties prenantes dans un environnement coopératif, les retards d'infrastructure et l'incertitude réglementaire), en fournissant des exemples concrets et en démontrant l'importance de les résoudre.

Le deuxième chapitre se concentre sur les stratégies mises en œuvre par les entreprises en place et les start-ups afin d'équilibrer la concurrence et la coopération dans l'écosystème du VA. D'une part, les entreprises en place ont intérêt à résoudre les goulets d'étranglement car ceux-ci limitent la croissance de l'écosystème, dont les entreprises en place tirent un avantage concurrentiel. Nous postulons que les entreprises allouent leurs investissements en capital-risque aux goulets d'étranglement. D'autre part, les startups sont conscientes des risques de d'appropriation de l'innovation lorsqu'elles forment des partenariats d'investissement avec les opérateurs historiques du marché, et utilisent différents mécanismes pour protéger leur innovation. Nous postulons qu'elles ont recours à une protection formelle et informelle de la propriété intellectuelle, comme les brevets, les connexions avec des tiers influents, la maturité de leur innovation et les marques déposées. Nous testons empiriquement ces hypothèses dans l'écosystème automobile émergent en utilisant une régression logistique pour mesurer la probabilité pour une startup de former un lien d'investissement en capital-risque d'entreprise (CVC). Les résultats suggèrent que les partenariats entre les startups et les entreprises en place sont plus susceptibles de se produire lorsque les startups développent la composante du goulot d'étranglement. Le fait de se concentrer sur les composantes du goulot d'étranglement permet aux entreprises établies de les résoudre, de créer et de capturer de la valeur au sein de l'écosystème et d'obtenir un avantage stratégique sur les écosystèmes concurrents. Ce résultat met en évidence la dynamique coopérative des écosystèmes : Pour qu'une proposition de valeur se concrétise, les entreprises ne peuvent innover seules et ont recours à la coopération pour améliorer la performance globale de l'écosystème. Nous confirmons également la présence d'une dynamique concurrentielle dans nos résultats : plus la maturité de la startup est élevée, plus la probabilité de formation d'un lien avec un CVC est élevée. De plus, nous constatons que les startups sont plus susceptibles de nouer des liens avec un CVC lorsqu'elles sont soutenues par des tiers bien connectés. Nous observons également que la probabilité de formation de liens est plus élevée lorsque les startups ont une activité de brevetage plus importante.

Le troisième chapitre se concentre sur les stratégies mises en œuvre par les acteurs publics pour surmonter les freins à l'adoption des véhicules électriques. Les gouvernements, les constructeurs automobiles et les opérateurs d'infrastructures ont déployé des initiatives visant à stimuler le marché afin de surmonter les obstacles qui entravent l'achat de véhicules électriques à batterie (BEV) et de véhicules électriques hybrides rechargeables (PHEV). Pour faire la lumière sur les principaux facteurs à l'origine de la lenteur de l'adoption des BEV et des PHEV, et sur l'efficacité des initiatives visant à stimuler le marché, nous utilisons une base de données originale et analysons statistiquement l'influence de 14 facteurs sociodémographiques, techniques et économiques sur les marchés des BEV et des PHEV nouvellement enregistrés, séparément, dans 94 départements français de 2015 à 2019, en utilisant une régression à effet mixte. Nous constatons que différents ensembles de covariables sont significativement corrélés aux parts de marché des BEV et des PHEV, respectivement, ce qui conduit à des interprétations différentes concernant la technologie du véhicule. Nous constatons que le nombre de modèles BEV/PHEV disponibles est positivement associé à l'adoption des BEV et PHEV. En revanche, le rapport entre le prix de l'électricité et celui de l'essence est associé négativement à l'adoption des BEV et PHEV. Alors que la densité des chargeurs rapides et ultrarapides et les incitations financières locales stimulent les ventes de BEV, la densité des chargeurs lents et normaux entraîne une augmentation des ventes de PHEV. En revanche, les incitations financières locales pour les PHEV, par rapport au prix des véhicules, ne stimulent pas les ventes.

Le quatrième chapitre se concentre sur les stratégies menées par les entreprises privées pour aligner leurs stratégies et façonner les réglementations, dans le contexte d'une innovation avec un cadre réglementaire très incertain. Nous analysons le comportement des entreprises développant des technologies de VA, en particulier lorsqu'il s'agit d'adopter une stratégie intégrée - alignant à la fois les stratégies marchandes et non marchandes - ou de s'en abstenir. Pour le développement de VA, les entreprises s'engagent dans des partenariats et forment des écosystèmes dans l'environnement de marché. En outre, elles participent à l'environnement non marchand afin d'influencer les décideurs politiques pour qu'ils adoptent la politique qui sécurise leur investissement. Nous nous concentrons sur le cas spécifique de la consultation publique de l'UE sur la mobilité connectée et automatisée, où les entreprises ont pu faire part de leurs préférences concernant deux sujets : la cybersécurité et la protection des données. Nous testons empiriquement la présence d'un alignement, sur les questions de cybersécurité et de protection des données, en analysant les réponses communes des entreprises à la consultation de l'UE pour chacun des sujets. Nous effectuons une analyse de réseau pour déterminer quelles entreprises appartiennent au même groupe lorsqu'elles répondent à la consultation. Nous effectuons ensuite une régression logistique pour déterminer les facteurs qui sont liés à l'alignement non marchand. Les résultats suggèrent que les entreprises sont plus susceptibles de s'aligner dans

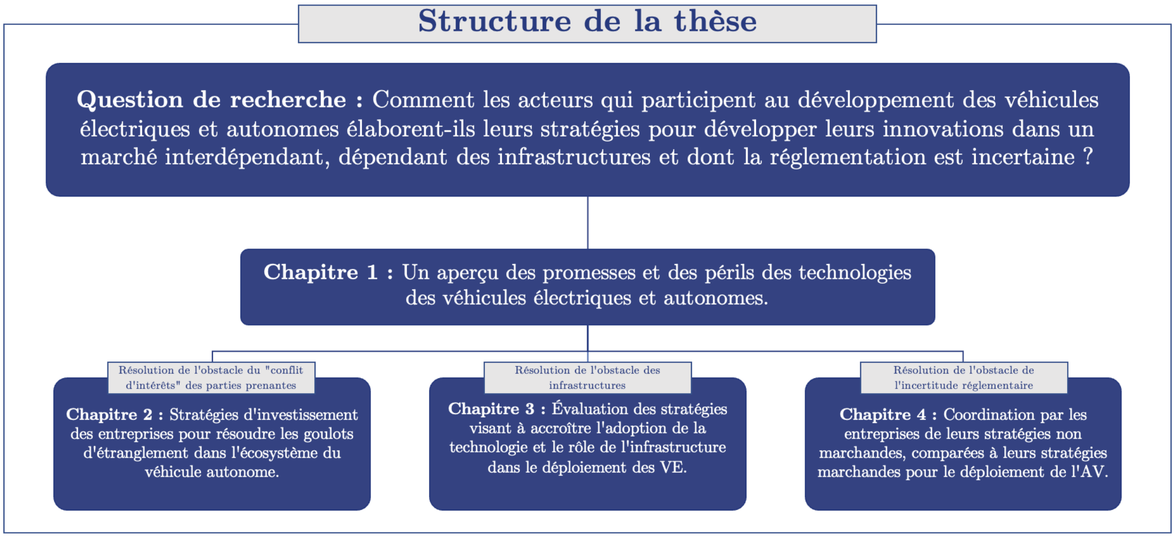

Figure 1: Structure de la thèse

leurs stratégies non marchandes lorsqu'elles appartiennent au même écosystème pour les questions de cybersécurité et de protection des données. De même, les entreprises appartenant au même secteur s'alignent dans leurs stratégies non marchandes. L'appartenance au même pays est un facteur pertinent pour l'alignement dans les stratégies non marchandes pour les questions de protection des données, tandis que la même taille est pertinente pour les questions de cybersécurité et de protection des données. Cette discussion se poursuit avec les principales contributions de cette thèse, les implications politiques et managériales, les limites de cette thèse, et propose de nouvelles directions de recherche.

Contributions

Tout d'abord, cette thèse contribue aux connaissances sur le développement des VE et VA. Ces deux innovations présentent des particularités similaires qui pourraient potentiellement révolutionner l'industrie de la mobilité. Cependant, se focaliser sur un pan de ces technologies ne parviendrait pas à saisir l'ensemble des différents défis de ces innovations. En faisant un tour d'horizon général de l'histoire, de l'état de l'art, des promesses et des périls de ces innovations, j'identifie les principaux obstacles au déploiement de la technologie : la divergence d'intérêts entre les parties prenantes, les obstacles liés à l'infrastructure et les obstacles réglementaires. L'une des principales conclusions de cette thèse pour le développement des VE et VA est que, pour résoudre ces obstacles, les entreprises collaboreront avec d'autres qui détiennent les connaissances sur la composante du goulot d'étranglement. Une autre contribution est que pour le déploiement des technologies, l'infrastructure doit être développée en parallèle. En particulier, dans le cas des voitures électriques à batterie, l'accent doit être mis sur l'installation de systèmes de recharge rapide et ultrarapide.

L'histoire est remplie d'innovations n'ayant pas réussi à s'imposer sur leur marché pour des raisons indépendantes de leur performance. Le VE est un bon exemple de ce phénomène. Au 19e siècle, les véhicules à moteur à combustion interne ont par exemple gagné la course contre les VE en partie grâce au réseau de routes et aux stations-service installées sur les parcours. Aujourd'hui, nous assistons à la réémergence des VE, et nous pouvons observer leur potentiel de décarbonisation de la mobilité à grande échelle. Les gouvernements du monde entier s'intéressent au déploiement des VE et VA, car elles sont essentielles pour atteindre leurs objectifs environnementaux. Par exemple, le "Green Deal" européen et compte beaucoup sur l'adoption de véhicules électriques pour atteindre les objectifs de réduction des émissions.

Toutefois, comme l'a souligné cette thèse, les acteurs privés se heurtent à plusieurs obstacles qui pourraient empêcher les innovations en matière de mobilité de se développer et les dissuader de participer au marché. Par exemple, l'installation d'une infrastructure de recharge, en particulier d'une infrastructure de recharge rapide et ultrarapide, nécessite des investissements élevés. En l'absence d'une masse suffisante de VE, les constructeurs automobiles, les exploitants de bornes de recharge et les fournisseurs de services de mobilité ne sont guère incités à installer l'infrastructure et à fournir le service. En outre, l'absence de réglementation sur ces marchés naissants se traduit par la diversité des modèles commerciaux et des technologies de soutien, ce qui pourrait entraîner des inefficacités, puisqu'il n'existe pas de consensus entre les acteurs publics et privés sur les exigences en matière de fourniture de services. Pour les VE, ces sous-marchés correspondent aux caractéristiques du véhicule, c'est-à-dire au remplacement de la batterie, aux stations de recharge ou à l'amélioration de la capacité de la batterie elle-même. Lorsque les marchés échouent ou peinent à s'organiser, les gouvernements peuvent intervenir en tant qu'orchestrateurs du marché. Cela soulève la question suivante : Le gouvernement doit-il favoriser l'adoption d'innovations pour servir l'intérêt public ? (Deleidi & Mazzucato, 2021).

La littérature antérieure suggère que lorsque des innovations sont en concurrence, à un moment donné, le marché se concentre sur l'une des technologies concurrentes (Arthur, 1989). Ceci se produit à l'entrée du marché lors du choix d'adoption d'une technologie par rapport à une autre. L'ordre des événements dans la sélection de la technologie dominante est également important. Par exemple, l'ordre d'arrivée d'un ensemble d'acteurs influence le résultat final de la compétition entre les innovations. Dans cette compétition, la meilleure technologie ne gagne pas nécessairement. C'est par exemple le cas de la machine à écrire QWERTY et du système d'enregistrement vidéo VHS, pour lesquels le marché s'est concentre sur une technologie inférieure à leurs alternatives. Sur le marché des VE, le facteur de différenciation évident entre les VE et les véhicules à moteur à combustion est l'infrastructure. L'infrastructure étant un facteur crucial pour l'adoption des VE, il est primordial pour le gouvernement de la prendre en compte pour promouvoir le développement à grande échelle.

Cette thèse contribue également à la recherche empirique naissante sur les écosystèmes. La littérature antérieure traite les goulots d'étranglement comme des événements isolés. Cependant, la prise en compte des interdépendances entre les entreprises, à travers la creation d'écosystèmes, nous permet de comprendre les défis de la coopération et de la concurrence dans un contexte de forte interdépendance, où les parties prenantes ont des intérêts divergents. En prenant le cas de l'écosystème du VA, nous observons l'interaction inexplorée entre les écosystèmes et le capital-risque des entreprises. Nous identifions que les entreprises utilisent le (i.e. capital-risque d'entreprise) pour résoudre les goulots d'étranglement au sein de leur écosystème. Nous contribuons également à cette littérature en ajoutant la dimension non-marchande. Les entreprises qui interagissent dans l'environnement non-marchand créent des alignements tacites avec d'autres acteurs privés au sein de leur écosystème.

Nous contribuons également à la littérature sur le management stratégique, car nous observons que la coopération, dans un contexte de concurrence, est très précieuse lorsque les entreprises développent des composants qui représentent des goulots d'étranglement pour l'écosystème. Néanmoins, nous montrons qu'elles utilisent des mécanismes de protection de la propriété intellectuelle pour se protéger des entreprises coopérantes. Dans le domaine non-marchand, une contribution importante est que les stratégies non-marchandes doivent être comprises comme individuelles, mais aussi collectives, lorsqu'il s'agit de stimuler une innovation.

Enfin, cette thèse utilise de nouvelles données qui, étant donné le stade précoce du marché, apportent une valeur ajoutée aux domaines des écosystèmes et du management stratégique, ainsi qu'au contexte du transport. Ces ensembles de données portent sur la formation d'écosystèmes par le biais de CVC et de partenariats stratégiques, sur les composantes des goulets d'étranglement, sur les stratégies non marchandes des entreprises dans le contexte européen, et sur les facteurs sociodémographiques, économiques et techniques susceptibles d'avoir un impact sur l'adoption des VE.

Implications politiques

Une implication politique clé concerne le rôle des gouvernements sur l'adoption des innovations. Tout d'abord, les gouvernements devraient fournir des incitations économiques, telles que des subventions et des réductions de taxes d'immatriculation pour l'achat de VE. Ces incitations politiques peuvent être mises en œuvre au niveau national ou local. De même, les gouvernements peuvent décourager l'achat de véhicules à moteur à combustion interne, par exemple en instaurant une taxe sur le carbone qui augmenterait le prix de l'essence et rendrait les véhicules à moteur à combustion interne plus coûteux pour les utilisateurs. Toutefois, l'augmentation de la taxe carbone peut entraîner des mouvements sociaux, comme ce fut le cas en France avec le mouvement des « Gilets jaunes », qui a poussé le gouvernement français à suspendre les taxes supplémentaires sur les prix des combustibles fossiles. Lors de l'élaboration des politiques, les gouvernements devraient discuter de leurs effets sur la population, en particulier sur les ménages à faibles revenus, et concevoir des mécanismes de redistribution pour la population affectée.

Deuxièmement, les gouvernements devraient jouer un rôle plus interventionniste en orchestrant le rôle des infrastructures de recharge publiques. Les gouvernements devraient encourager les acteurs privés à installer des chargeurs ultrarapides sur les autoroutes pour les VE, des chargeurs rapides dans les zones urbaines pour les VE, et des chargeurs lents et normaux pour les VHR. En utilisant des instruments comme les appels d'offres publics, ils peuvent organiser le marché des infrastructures de recharge en incitant les acteurs privés à participer à l'exploitation de l'infrastructure et au déploiement des services, et en servant l'intérêt public de la décarbonisation.

Enfin, les décideurs politiques plus largement peuvent contribuer à définir le marché en définissant des règles claires pour le déploiement des innovations. Nous avons en effet observé que les parties prenantes de l'écosystème du VA ont des intérêts divergents en ce qui concerne les sujets sensibles comme la cyber sécurité et la protection des données. Cependant, ces ensembles de règles doivent être conçus en tenant compte du comportement des parties prenantes lorsqu'elles font pression sur les régulateurs. En effet, les décideurs politiques devraient prendre en considération le fait que les partenariats entre acteurs privés de l'écosystème pourraient expliquer leurs stratégies de lobbying. Les consultations publiques sont des outils utiles aux pour recevoir des contributions d'organisations inscrites dans différents secteurs et présentant des caractéristiques différentes. Sur la base de ces outils, les régulateurs et les décideurs publiques ont tendance à privilégier l'option qui favorise les intérêts de la majorité des acteurs. Toutefois, il faut tenir compte du fait que les entreprises combinent stratégiquement leurs stratégies marchandes et non marchandes. Par conséquent, une solution institutionnelle qui favorise la majorité n'est pas nécessairement la meilleure.

Implications managériales

Ces dernières années, le potentiel des technologies des VE et VA a attiré l'attention de multiples acteurs de différents secteurs. Cependant, les acteurs reconnaissent les obstacles à leur mise en œuvre. Ils existent des opportunités de développement au vu du potentiel de création de valeur, mais les coûts élevés de leur mise en place peuvent constituer des freins à leur développement.

Le premier enseignement managérial est que les parties prenantes doivent coopérer afin de participer au marché, car elles n'ont pas toutes les compétences pour innover par elles-mêmes. Le CVC est un instrument qui permet aux entreprises de coopérer avec d'autres, notamment avec des start-ups spécialisées dans le développement des technologies. L'utilisation de cet instrument est encore plus cruciale lorsqu'il s'agit d'accéder à un composant goulot d'étranglement. Grâce à ce type de collaboration, les organisations peuvent résoudre le goulet d'étranglement et faire évoluer l'écosystème.

La coopération est cruciale non seulement dans l'arène marchande, mais aussi dans l'arène non marchande. Comme le montrent les résultats de cette thèse, au début du déploiement des innovations, les entreprises sont incitées à s'aligner sur leurs partenaires de l'écosystème pour créer de la valeur au sein de celui-ci. Pour les grandes entreprises, l'atteinte de ce résultat est plutôt évidente. En effet, connaissant l'environnement de marché, elles savent que des coalitions sont possibles lorsqu'elles font pression sur le régulateur, et disposent de suffisamment d'instruments pour mettre en place des stratégies sophistiquées hors marché. Cependant, pour les petites entreprises, le développement de stratégies non marchandes efficaces au sein d'un écosystème peut être plus complexe. Les petites entreprises doivent être en mesure d'identifier ces coalitions afin d'en tirer parti et ainsi mettre en place leurs stratégies de lobbying.

D'autre part, la coopération peut entraîner des risques d'appropriation illicite, puisque les grandes entreprises ont intérêt à disposer d'informations sur le principal atout de la startup, à savoir l'innovation en soi. Dans ce cas, les startups devraient se protéger contre l'appropriation illicite en utilisant des mécanismes formels (c'est-à-dire des brevets) et informels (c'est-à-dire la maturité de leur innovation et les connexions avec des tiers influents) pour éviter le détournement.

Enfin, cette thèse a mis en évidence plusieurs facteurs qui motivent les adoptants potentiels des VE à les acheter. L'un de ces facteurs est la disponibilité des modèles de VE. Le mécanisme sous-jacent est qu'une plus grande disponibilité des modèles peut accroître la sensibilisation des utilisateurs potentiels et la visibilité de la marque du fabricant. Par conséquent, les constructeurs automobiles pourraient augmenter leurs ventes de VE en proposant un plus grand nombre de modèles de VE, avec différentes tailles, styles, capacités de batterie et conceptions. Cette recommandation implique d'engager des coûts de R&D et de fabrication, mais ils pourraient gagner de nouveaux clients et aider une entreprise à se différencier de ses concurrents.

Limites

Cette thèse présente toutefois certaines limites. Dans ce travail, nous avons fourni un panorama des stratégies menées par les acteurs de l'écosystème de la mobilité électrique et autonome pour faire évoluer les innovations de cet écosystème. Malgré l'utilisation de différentes perspectives dans les sphères privées et publiques, tous les acteurs cruciaux de cet écosystème n'ont pas été considérés dans cette recherche. C'est le cas par exemple de certaines entités publiques locales ou encore des fournisseurs d'énergie. Or, on sait par exemple que les municipalités jouent un rôle important dans la mise à l'échelle des innovations en matière de mobilité. Les stratégies des municipalités comprennent l'engagement dans des projets de mobilité avec des acteurs privés pour améliorer leur service de transport public, entre autres, et elles permettent de tester et d'inclure des voitures électriques et autonomes dans leur périmètre urbain. De même, certaines des stratégies utilisées par les acteurs participant au marché n'ont pas été intégrées au périmètre de cette recherche. Or, on sait que de telles entreprises utilisent d'autres instruments, en dehors des programmes de capital-risque d'entreprise, pour résoudre les goulots d'étranglement technologiques, comme les alliances stratégiques, les alliances de R&D ou les acquisitions. L'effet des autres stratégies de coopétition n'est pas exploré dans cette recherche.

Les innovations sont soumises à des facteurs externes qui peuvent modifier le succès ou l'échec de leur mise en œuvre. Nous avons observé tout au long de l'histoire des VE que la performance technique, qui est généralement un facteur clé dans le choix des types de véhicules, n'était pas pertinente dans les années 1930 pour le choix entre les moteurs à combustion interne et les voitures électriques. Au contraire, la construction de routes et d'installation de stations-service ont favorisé la création d'un écosystème propice au véhicule à moteur à combustion interne, par rapport aux véhicules électriques. De même, le rôle des autres technologies concurrentes n'a pas été pris en compte dans cette recherche. Par exemple, le rôle des véhicules à hydrogène par rapport aux voitures électriques, ou encore les progrès des biocarburants ou les améliorations de l'efficacité énergétique des véhicules à moteur à combustion interne n'ont pas été considérés. Cette question a des implications dans la stratégie des acteurs participant à l'écosystème des VE, car ils ne sont pas seulement en concurrence avec les entreprises proposant des technologies alternatives, mais aussi parce qu'ils pourraient diversifier leurs activités et participer à l'écosystème des technologies alternatives.

Néanmoins, les technologies alternatives sont également confrontées à des inconvénients techniques et socio-économiques. Les véhicules à hydrogène, ou véhicules électriques à pile à combustible (FCEV), rencontrent plusieurs obstacles qui pourraient entraver leur déploiement. Tout d'abord, les FCEV subissent des pertes d'énergie plus importantes que les VE. Le rendement énergétique des véhicules à hydrogène peut varier de 15 à 54 %, depuis la production d'électricité par électrolyse jusqu'à sa conversion en chevaux-vapeur pour le véhicule. Même en tenant compte des avancées technologiques en matière d'efficacité énergétique de l'hydrogène, les FCEV ont besoin de 2,5 à 3 fois plus d'énergie que les véhicules électriques à batterie (Bigo, 2020; European Federation for Transport and Environment AISBL, 2018). Le coût des véhicules à hydrogène est également important. Le coût total de possession d'un FCEV est 40 à 90 % plus élevé que celui d'un ICEV et d'un BEV, bien que les prévisions suggèrent qu'il sera inférieur d'ici 2026 (Ballard & Deloitte, 2020). Ils nécessitent également un réseau de stations de ravitaillement pour les voitures à hydrogène, ce qui pose le même dilemme de la poule et de l'œuf que pour les véhicules électriques à batterie. Le déploiement comporte également un risque plus élevé, car l'hydrogène est un gaz hautement explosif. Bien que l'hydrogène soit déjà utilisé à des fins industrielles ou pour le transport de charges lourdes (c'est-à-dire le transport maritime), le risque d'inflammabilité est plus élevé pour les véhicules légers personnels. Enfin, 94 % de la production d'hydrogène se fait à partir d'énergies fossiles, par reformage à la vapeur, oxydation d'hydrocarbures liquides ou gazéification du charbon (Bigo 2020, Deloitte et Ballard 2020). Les pays et les régions du monde sont conscients des avantages et des inconvénients des technologies de décarbonisation concurrentes pour les véhicules légers personnels, et certains d'entre eux ont déjà commencé à privilégier l'une ou l'autre des nombreuses technologies. Le choix de l'Europe est clair. Dans sa stratégie en faveur de la mobilité durable et intelligente, l'UE soutient principalement les véhicules électriques à batterie et les véhicules électriques plug- in-hybrides plutôt que les véhicules électriques à pile à combustible pour le transport routier léger. Plusieurs projets sont en place pour accroître les incitations à l'adoption des VE, et les États membres de l'UE lancent des appels d'offres publics pour l'installation de plans d'infrastructure de recharge des VE afin d'accroître le réseau sur les routes européennes.

La reproductibilité de cette étude est une autre limite potentielle. Bien que les VE et VA présentent des caractéristiques similaires en ce qui concerne la forte interconnexion entre les parties prenantes au sein de leur écosystème ou la grande incertitude réglementaire, il faut observer que certains des problèmes auxquels ils sont confrontés sont toutefois singuliers. En particulier, ils impliquent l'utilisation d'une ressource rare : le sol. En raison de la capacité de ces innovations à réduire le nombre de voitures et à changer complètement la dynamique urbaine, les questions relatives à l'installation des infrastructures, à l'affectation des routes, à la répartition de l'espace urbain, sont des questions propres à la mobilité. Cela exerce une influence sur le comportement des différents acteurs et les stratégies utilisées. En outre, nous ne pouvons pas généraliser nos résultats à un autre contexte régional ou national, en dehors de ceux déjà couverts dans cette recherche, en raison des différences institutionnelles, culturelles et sociodémographiques.

Voies de recherches futures

Sur la base de ses contributions et en tenant compte de ses limites exposées précédemment, cette thèse ouvre plusieurs pistes de recherche qui méritent d'être explorées en même temps que l'évolution de la mobilité électrique et autonome. L'une des promesses de la mobilité électrique et autonome est qu'elle peut créer des synergies avec les transports publics pour transformer la façon dont les gens se déplacent et la façon dont les villes sont organisées. Actuellement, les municipalités font pression pour des solutions de multimodalité entre les différentes formes de transport afin de proposer un transport public plus efficace qui puisse remplacer la possession d'une voiture. Pourtant, très peu d'études se sont concentrées à ce jour sur l'analyse des solutions multimodales et leur impact réel dans les espaces urbains. Par conséquent, les questions liées à la conception du marché, aux modèles commerciaux, à l'efficacité et à l'impact des solutions multimodales constituent une voie prometteuse pour de futures recherches. L'une des caractéristiques faisant du transport un domaine d'étude unique est qu'il implique l'utilisation du sol, qui est une ressource rare dans les espaces urbains. Étant donné que les VE et VA représentent une opportunité de réduire le nombre de voitures dans les espaces urbains, de nouvelles questions concernant l'utilisation de l'espace se posent à l'issue de cette thèse. Ces innovations nécessitant l'installation d'infrastructures et l'allocation de routes, il serait donc intéressant d'analyser les moyens par lesquels les espaces urbains s'adapteront à l'entrée des innovations.

Comme le montre le cycle technologique (Abernathy & Utterback, 1978), l'incertitude diminue avec le temps et les innovations s'établissent ou périssent. Les stratégies des entreprises changent au fil du temps avec la constitution et la maturation d'un écosystème. La logique de création de valeur que nous avons observée dans les résultats de cette thèse peut passer à la capture de valeur une fois que les différentes entreprises parviennent à établir les innovations comme la technologie dominante. Parallèlement aux technologies, des réglementations sont également établies, ce qui réduit l'incertitude pour les parties prenantes. Cette thèse se concentre uniquement sur les premiers stades des innovations. L'analyse du comportement marchand et non marchand des parties prenantes en prenant en compte les aspects dynamiques des technologies et l'évolution de la réglementation est une perspective intéressante pour de futures recherches.

Tout au long de cette recherche, nous avons examiné différentes stratégies utilisées par les parties prenantes pour éliminer les obstacles qui pourraient entraver le développement des innovations. Cependant, nous n'avons pas comparé l'efficacité et la faisabilité de ces stratégies. Par exemple, alors que le développement de certaines stratégies nécessite des investissements élevés pour les acteurs publics, tels que l'installation d'infrastructures, d'autres nécessitent une forte acceptation du grand public, comme les taxes sur le prix de l'essence. Ainsi, de futures recherches pourraient mener une analyse coûts-avantages des différentes stratégies afin de déterminer la mesure la plus efficace à mettre en œuvre.

L'évolution des VE et VA offrira de nombreuses possibilités de création de valeur et donnera naissance à divers modèles commerciaux. Une analyse de la durabilité et de l'efficacité des différents modèles économiques est une autre question de recherche intéressante à explorer. En outre, bon nombre des modèles économiques qui apparaissent placent l'utilisateur au centre. Par conséquent, une autre question clé à explorer est l'avis des utilisateurs sur les technologies, les motivations intrinsèques qui les amènent à choisir entre les technologies et comment façonner leur comportement pour augmenter l'acceptabilité et l'évolutivité des technologies. Une autre question mentionnée mais peu explorée dans cette recherche est la justification de l'intervention publique. Les acteurs publics ont joué un rôle actif dans l'intégration des innovations en matière de mobilité. Leur intervention peut être jugée nécessaire pour favoriser la meilleure technologie sur le marché. Les justifications, les mécanismes et les résultats de leur intervention sont une question qui peut être analysée plus en détail dans le contexte de technologies concurrentes.

Enfin, parallèlement aux VE et VA, d'autres types d'innovations en matière de mobilité, comme les véhicules à hydrogène, émergent sur le marché. Bien que l'UE ait clairement choisi de soutenir les VE pour la décarbonisation du transport individuel léger, les véhicules à hydrogène restent une solution possible pour les véhicules lourds et d'autres types de modes de transport. Les parties prenantes qui participent au développement des VE et VA ont également des projets en cours pour améliorer la technologie des véhicules à hydrogène. Parallèlement, de nouvelles parties prenantes, à savoir des start-ups, se consacrent exclusivement à la recherche et au développement de véhicules à hydrogène. Sur ce marché, nous observons des schémas similaires de formation d'écosystèmes entre des parties prenantes ayant des intérêts divergents, des besoins en infrastructures et des problèmes de réglementation. Un exemple est le consortium Hydrogen Europe, qui a pour objectif d'accélérer les industries européennes de l'hydrogène et qui comprend 315 entreprises, dont Airbus, Audi, BMW, BP et la société espagnole de services publics Iberdrola. De nouvelles questions de recherche peuvent émerger dans ce contexte, par exemple concernant la décision d'entrer sur les différents marchés et la manière dont les parties prenantes font avancer et privilégient l'une ou l'autre ou les deux technologies de substitution.

GENERAL INTRODUCTION

Mobility is undergoing a transformation due to three main drivers. Firstly, electric and hydrogen propulsion systems are replacing fossil-fueled engines in vehicles. Secondly, the data revolution and sophisticated new technologies allow for vehicles to communicate with anything that can be connected (e.g. infrastructures, other vehicles, pedestrians, etc.). Thirdly, the degree of human intervention in the driving process is becoming nonessential, leading to the replacement of human-driven cars by autonomous vehicles.

In the past decade electric and autonomous vehicle technologies have gained momentum since they provide an opportunity to create value, while solving some of the world's greatest mobility problems. Electric vehicles (EVs) reduce local air pollution, traffic noise, and could eventually reduce GHG emissions, when coupled with a low-carbon electricity sector (Hawkins et al., 2013). Autonomous vehicles reinvent the way people work and spend their leisure time, have the potential to reduce traffic accidents, increase access to vulnerable populations and cover areas underserved by public transport (J. Anderson et al., 2016). In addition, one can expect to observe synergies between both innovations. Even though autonomous vehicles do not necessarily need to be electric and vice versa, electric vehicles could boost autonomous mobility. Electric vehicles are safer, more sustainable and require less maintenance. In parallel, autonomous vehicles boost electric mobility, by increasing the various applications and services offered and by increasing their energy and time efficiency, making them more sustainable. If integrated, we can expect these innovations to change not only the way we move, but also the way we work, the services we consume and potentially redesign the cities we live in, just as motor cars did before them.

However, despite the advantages of electric and autonomous mobility, a widespread transition to both innovations has not yet happened. For instance, since electric vehicles became a promising nascent market in 2010, adoption has been slow. Global EV market share reached just 4.6% in 2020, and the number of personal electric vehicles represent less than a 1% of all cars in circulation worldwide (IEA, 2021a). There are only a few exceptions. In Norway, EV sales corresponded to 56% of total vehicle sales in 2020 and EVs represented 13% of the total number of cars in circulation (IEA, 2020). Regarding autonomous vehicles, adoption and acceptance has also been slow. While in 2010, prospects were optimistic for the update of autonomous vehicle technologies, by the end of the decade there is a more realistic view. Up to now, autonomous vehicles are passing through the testing and development phase and no company is at the mass-production stage. Indeed, many stakeholders' plans to mass-market AV technology were postponed to future dates.

Part of the lag in the up-scaling of those innovations can be attributed to their technical performance. In the case of electric vehicles, concerns have been placed on the driving range[7], on the battery energy density[8], and on charging times of the vehicle. For autonomous vehicles, a technology that ensures that the vehicle is able to perceive its environment better than the best human drivers is complex to develop. Computer vision and detailed maps ensuring safe AVs remain a major challenge at this point. For instance, the capability to accurately detect and classify objects in uncommon situations is a challenging task that requires a large set of tests and data for the vehicle to master. Lastly, autonomous vehicles need to communicate in real-time. Choosing the right communication technology that would allow the vehicle to give an immediate response to receptors and manage large amounts of data in a very short time are some of the challenges to overcome. Up to now, companies have released beta versions of the technology and try to test it in all possible scenarios. However, the previous underestimation of technological difficulties, leading to fatal accidents involving autonomous systems, has contributed to a decay in optimism. Nonetheless, some technological advancements have allowed for those issues to becomes less of a concern. The battery density of some the 2018-2019 versions of the most common electric car models is 20-100% higher than their 2011-2012 equivalents (IEA, 2020). Thanks to the progress of fast charging, charging times can decrease considerably[9]. Recent technologies even power EVs to an 80 percent charge in 15 minutes, on average (Tritium, 2020). In a similar trend, technological advances on autonomous vehicle technology have been significant. For instance, Nvidia's platform DRIVE PX AI[10] is 10 times superior to its

[7]Driving range is the distance an EV can drive with the energy stored in its battery.

[8]Battery energy density is the amount of energy carried within a given size or weight of a battery.

[9]Charging times can decrease at a rate 250-500 kW for cars being deployed or announced, an advance from the 50-120 kW capacity of most current electric car models.

[10]Nvidia Drive is a computer platform by Nvidia, aimed at providing autonomous car and driver assistance func-

predecessor DRIVE PX 2 (Pal, 2018).

The innovation literature has indeed long recognized that technologies' performance is important but not sufficient for successful diffusion or upscaling (Montalvo, 2008). Socio-institutional challenges and infrastructure challenges are crucial for the transition towards new technologies. Three main socio-institutional barriers can delay the transition towards new technologies: stakeholders' mismatch of incentives in an ecosystem, infrastructure lags and regulatory uncertainty.

First, the transformation of mobility is not only the playing field of automakers and automotive suppliers but also of new and emerging actors coming from different sectors. For instance, the development of autonomous vehicles is driven by automakers (e.g. Renault-Nissan, Tesla and BMW), hardware providers (e.g. Delphi, Intel and Nvidia), software providers (e.g. Apple, Microsoft and Waymo), and car-hailing companies (Didi Chuxing, Uber and Lyft). Stakeholders involved are becoming more dynamic and interdependent (Adner, 2017; Iansiti & Levien, 2004). Each of the actors draws on their capabilities to develop different components that form the focal product, and choose to cooperate in certain components, by creating strategic alliances or committing strategic investments, instead of developing the entire product by themselves. Some of the components, the "bottleneck components", might constrain or hinder the development of the focal product. For example, the capacity to identify and classify objects like a human eye is a component that could compromise the entire functioning of autonomous vehicles. In the presence of a bottleneck component different actors may need to cooperate to further develop the focal product. Yet, actors in the mobility ecosystem are motivated by different and sometimes conflicting, incentives. This makes collaborations more difficult. For example, to advance the development of a bottleneck component large firms that lack specialized expertise can invest in startups specialized in the bottleneck component to help resolve the bottleneck. But startups cooperating with large firms face the risk that the large firms may abuse their market position to hinder innovations or slow down their development because it corresponds to their interest. Balancing cooperation and competition becomes crucial in this setting. In the mobility ecosystem, innovations rely on the use and coordination of scarce resources, such as

tionality powered by deep learning.

land. Therefore these innovations differ from innovations in other markets, e.g. in digital markets. Because of the reliance on land public actors play a role in mobility ecosystems. In this setting, another layer of difficulty is thus added to the coordination of incentives among actors, public and private.

Second, innovations require considerable infrastructure changes that are costly to implement. Electric vehicles require the installment of charging stations along the roads. Likewise, autonomous vehicles require roads adapted for cameras and sensors to operate vehicle-to-infrastructure (V2I) communications networks, and 5G networks to avoid communication lags among vehicles and their environment. In case the technologies are supposed to be coupled with the public transportation network of a municipality, changes in this transportation network also need to be foreseen. This represents high cost for market participants to incur and means they have to operate with sunk cost[11] for a long time. While sunk cost present a problem to market participants, these technologies could benefit from economies of scale[12], if widespread. However, so far the technologies are not widespread but an a relatively early stage. At early stages of the innovation, there is uncertainty on the future patterns of consumer behavior. Therefore market participants and their investors are reluctant to commit resources until there is a well-established market. This is the case for electric vehicles, where potential users are reluctant to buy EV until there are enough charging stations and market players are reluctant to install more charging stations until there are enough EV on the roads to serve. So, what should come first: the vehicles or the charging station? This resembles the famous chicken-and-egg dilemma and remains one of the major barriers for electric vehicles' diffusion on a large scale.

Third, regulations are not up-to-date with innovations. The regulatory process is generally a slow process, given the cycles of proposals, requests for comments, reviews and lobbying that precede rule-making. Especially with new technologies, which are complex and evolve rapidly, there is high uncertainty on the outcome, and prescribing rules that can remain relevant is challenging (J. Anderson et al., 2016). The multiplicity of stakeholders also adds complexity in the

[11]Sunk cost is a cost that has already been incurred and cannot be recovered.

[12]Economies of scale are cost advantages reaped by companies when production becomes efficient. Companies can achieve economies of scale by increasing production and lowering costs. This happens because costs are spread over a larger number of goods. Costs can be both fixed and variable.

regulatory process, since they have diverging interests. Some of the actors can be resistant to regulation, since they claim that technologies do not necessarily evolve in the expected direction, and regulation can hinder technology development. However, regulations could also give clarity to manufacturers on how and when the technology will work, and provide signals to people that interact with the given technology. For instance, vehicle safety regulations would permit self-driving software manufacturers to program their cars to act within the bounds suggested in terms of vehicle speed. Similarly, regulations are also important to ensure cybersecurity, data protection and access. They must ensure a balance between vehicle data sharing that enables fair competition in the provision of services, while ensuring compliance with the legislation on the protection of personal data. They could also determine who holds the responsibility for which actions in case of an accident. To understand the details of the technologies, regulators need the input from companies in the market. Regulators provide instruments like consultations to give feedback on rule-making. However, companies naturally have different incentives and this affect how they communicate with the regulators.

Actors participating in the mobility ecosystem are aware of these challenges and have put in place different strategies to meet them. Throughout this thesis, I explore the strategies used by actors in order to overcome the socio-institutional challenges of the transition towards a modern mobility sector. Hence, I would like to answer the following question: *How do actors participating in the electric and autonomous vehicle development shape their strategies to scale-up innovations in an interdependent, infrastructure-dependent, and regulatory-uncertain market?*

I explore this question with three different perspectives, each corresponding to a chapter of this thesis. Each of the chapters concentrates on one of the three bottlenecks for the aforementioned up-scaling: stakeholders' mismatch of incentives in a cooperative environment, infrastructure lags and regulatory-uncertainty.

The first, introductory chapter provides the background for the three perspectives: an overview of both electric and autonomous vehicle technologies. It starts by underlying the role of transportation in our economy. Subsequently, it gives an overview of the technologies' history and state-of-the-art, to provide a general picture of their evolution and today's stakes. Then, it explores the potential of both EVs and AVs to create value. Lastly, it evokes the three barriers for up-scaling mentioned above (i.e. stakeholders' mismatch of incentives in a cooperative environment, infrastructure lags and regulatory-uncertainty), by providing concrete examples and highlights the importance to resolve them.

The second chapter focuses on the strategies undertaken by both incumbents and startups in order to balance competition and cooperation in the autonomous vehicle ecosystem. On one hand incumbent firms are interested in resolving bottlenecks. Incumbents have incentives to resolve bottlenecks since they restrict the ecosystem's growth, from which the incumbents gain competitive advantage. We posit that firms allocate corporate venture capital investments towards bottlenecks. On the other hand, startups are aware of the risks of misappropriation of the innovation when forming investment partnerships with incumbents in the market, and use different mechanisms to protect their innovation. We posit that they resort to formal and informal intellectual property protection, such as patents, connections to influential third parties, the maturity of their innovation and trademarks. We empirically test these hypothesis in the emerging automobile ecosystem by using a logistic regression to measure the likelihood of any startup to form a corporate venture capital (CVC) investment tie with any CVC. Results suggest that partnerships between startups and incumbents are more likely to occur when startups develop the bottleneck component. Focusing on the bottleneck components allows established firms to resolve them, create and capture value within the ecosystem and gain strategic advantage over competing ecosystems. This result highlights the cooperative dynamics of ecosystems: For a value proposition to materialize, companies cannot innovate alone and resort to cooperation to improve the overall performance of the ecosystem. We also confirm the presence of competitive dynamics in our results. We also confirm the presence of competitive dynamics in our results: the higher the maturity of the startup at the focal round, the higher the likelihood of tie formation with a CVC. In addition, we find that startups are more likely to tie with a CVC when they are backed by well-connected third parties. We also observe that the likelihood of tie formation is higher when startups have a higher patenting activity.

The third chapter focuses on the strategies undertaken by public actors to overcome infrastructure lags and foster adoption. Governments, automotive manufacturers, and charging infrastructure operators have deployed market-boosting initiatives to overcome barriers hindering purchasing activity of Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). To shed light on the main factors causing the slow uptake of BEVs and PHEVs, and on the effectiveness of market-boosting initiatives, we use an original database and statistically analyzed the influence of 14 socio-demographic, technical, and economic factors on the newly-registered BEV and PHEV markets, separately, in 94 French departments from 2015 to 2019, using mixed-effect regression. We find different sets of covariates to be significantly correlated with BEV and PHEV market shares, respectively, leading to different interpretations regarding the vehicle's technology. We find that the number of available BEV/PHEV models is positively associated with BEV and PHEV adoption. Contrarily, the ratio of electricity prices with respect to gas prices is negatively associated with BEV and PHEV adoption. While fast and ultrafast chargers density and local financial incentives boost BEV sales, slow and normal chargers density lead to higher PHEV sales. On the contrary, local financial incentives for PHEVs, relative to vehicles' prices, do not boost sales.

The fourth chapter focuses on the strategies undertaken by private firms to align their strategies and shape regulations, in the context of an innovation with a highly uncertain regulatory framework. We analyze the behavior of firms developing autonomous vehicle technologies, specially when it comes to adopting an integrated strategy–aligning both market and non-market strategies, or opting out of it. For the development of autonomous vehicles, firms engage in partnerships and form ecosystems in the market environment. In addition, they participate in the non-market environment to influence policy-makers to adopt the policy that secures their investment. We concentrate on the specific case of the EU public consultation on connected and automated mobility, where firms could inform their preferences regarding two topics: cybersecurity and data protection. We empirically test for the presence of an alignment, in cybersecurity and data protection issues, by analyzing the common responses of firms to the EU consultation for each of the topics. We perform a network analysis to determine which firms belong to the same cluster when responding to the consultation. We then perform a logistic regression to determine the factors that are interrelated with non-market alignment. Results suggest that firms are more likely to align in their non-market strategies when they belong to the same ecosystem for both cybersecurity and data protection issues. Similarly, firms belonging to the same sector align in their non-market strategies. Belonging to the same country is a relevant factor for alignment in the non-market strategies for data protection issues, while having the same size is relevant for cybersecurity issues.

Finally, the general conclusion highlights the contributions, the policy and managerial implications, the limitation of this thesis, and proposes further research directions.

CHAPTER 1
THE PROMISES AND PERILS OF ELECTRIC AND AUTONOMOUS VEHICLE TECHNOLOGIES

1.1 Introduction

Transportation plays a major role in people's life. It is hard to imagine a life without transport, as it is an intrinsic activity of humans, an enabler of civilizations, and a basis for economic and social activities. Through time, humans have come up with ideas to move around objects or themselves from one place to another. At first, humans carried out these activities by walking or swimming and created trails for that purpose. Innovations allowed transport to evolve to what we know now. For instance, in road transport, the domestication of animals instituted a new way to move goods and people. With animal transport, humans increased the efficiency of transportation and started adapting trails for animals passing through. As exploration to farther areas was possible, the need to advance further was also heightened. Trade also grew in size and scope, raising, even more, the need for more efficient transportation means. Thus, innovations, like paved roads and later motor vehicles, were necessary to supply the increasing demand for transport and reduce the costs related to animal-related transport. Other means of transport (i.e. rail, water or air) have followed the same logic: innovations seek to increase transport efficiency and reduce costs.

Transportation activities are tightly linked to economic growth. In the EU, transport accounts for about 5% of GDP and directly employs around 10 million people (EC, 2011). In France, the transportation sector accounted for 1.4 million direct jobs in 2018, corresponding to 5.2% of the total number of jobs (Bigo, 2020). In the U.S. transportation-related activities correspond to 5.6% of GDP (BTS, 2017). The COVID-19 pandemic exhibited the strong links between transportation and the economy. At the end of March 2020, road transport activity decreased by almost 50% compared to 2019 levels in France. In Europe, international coach transport and national passenger transport markets were largely hit by the social distancing restrictions, resulting in a 100% decline in tourist services and a nearly half decrease in inter-city services. Other transport modes were also greatly affected by the COVID-19 restrictions, such as rail, air and maritime transport. To mitigate the adverse effects of the pandemic, the Commission approved on April 2020 a package of measures directed toward the aviation, rail, maritime, and road sectors. Research in the U.S. suggests that workers in the transportation sector were 20.6 percent more likely to be unemployed due to the pandemic than workers in non-transportation industries. There is also evidence of heterogeneities in unemployment levels within the different transportation occupations. The likelihood of unemployment compared to essential workers was 28 times higher for taxi and limousine drivers, 23.8 times higher for scenic and sightseeing workers, 84% lower for postal workers and 67% higher for pipeline workers.

At present, transportation is passing through a major revolution. There is an opportunity to create value for consumers with new technologies and services, and at the same time reduce the negative externalities linked to transport (i.e. emissions, pollution, congestion and traffic accidents). Technologies like electric, autonomous and connected vehicles are opening the possibilities for a cleaner, safer, service-oriented, multimodal transport system. Political frameworks around the world are including roadmaps to make the transport system more resilient and adapted to current priorities (such as environmental goals) while ensuring competitiveness (i.e. in the case of the EU with its *Strategy for Smart and Sustainable Mobility*, as part of the European Green Deal). Changes in working habits due to the COVID-19 pandemic have reshaped the way people travel daily and discouraged the use of transportation means. Consumer habits have also shifted, especially with the popularization of e-commerce. In the U.S., transborder freight increased 21% in August 2021 compared to August 2020, and 7.6% compared to August 2019 (pre-pandemic) (BTS, 2021).

The future of transport is expected to be more sustainable, more apt to new working and consumption habits, and open to new business models (i.e. mobility as a service (MaaS)). Within all the issues that entail this revolution, I focus my thesis, and this chapter in particular, on electric and autonomous mobility. Both technologies have already been developed and are far from being just a fictional unattainable concept. Electric vehicles were introduced more than 100 years ago and competed head-on with Internal Combustion Engines (ICE). After a long decline in their interest, falling behind from internal combustion engine vehicles, EVs made their comeback at the beginning of the 21st century, showing a promising potential to achieve zero-net emission goals in transport. Likewise, autonomous vehicles made their debut in the 1980s, providing a promising solution to revolutionize consumption patterns, save driving time, and increase accessibility to disabled and elderly populations, while at the same time promising to reduce crashes, reduce congestion, and lower emissions and save fuel. Coupled with shared mobility, they have the potential to diverge from the privately-owned car to become a service. A transition to autonomous vehicles brings a change in behaviours with respect to working habits, eating patterns and entertainment consumption. To understand the current issues of both technologies and their importance for research, this chapter will explore their definition, their history, their potential usages, their added value, their capability to reduce transport-related externalities and their deployment barriers.

1.2 Electric and autonomous vehicles through the lenses of technological progress

The scope of this dissertation focuses on electric and autonomous vehicle technologies. We can consider both technologies as innovations, but instead of "radical", we can view them as "evolutionary", since they are a compound of old and new ideas. According to Abernathy and Utterback (1978), innovations follow three phases: The first phase corresponds to the *fluid phase*, where there is a radical product innovation, but there are uncertainties regarding the technology and the market. In this phase, multiple outcomes of the main innovation emerge and there is rivalry among different manufacturers on what will be the adopted design. Stakeholders involved will then implement different strategies to attempt to establish their product as the "dominant design". The next phase is the *transitional phase*, which sees the emergence of the dominant design, since there are convergence signals coming from producers knowing more about the market and application and customer needs, and standardization starts to appear. For manufacturers, it is important to win the battle over the dominant design, since it will allow them to collect monopoly rents. The monopoly rents result from the situation when the dominant design is not easily imitated and they can recur to IP protection rights. In this phase, there is radical process innovation and incremental product innovation. Finally, the *specific phase*, which already saw the emergence of the dominant design, will concentrate on product performance and costs. In this stage, we observe both incremental process and product innovation. Companies will focus on providing certain clients as they have a clear view of the market segments.

Similarly, P. Anderson and Tushman (1990) proposed a dynamic model of technological progress, which along with other studies, translate technological trajectories into S-curves. This approach holds that for a fixed level of effort or time, the performance improvement of a technology is low at the early stage of development. Then, it increases as understanding of the technology increases, until it reaches a maturity stage where additional effort brings decreasing returns to the performance improvement of the technology. The model also describes different phases of technological progress: The era of ferment, where a radical innovation is introduced but it is in an experimental level. The era of ferment ends as soon as the dominant design emerges, and a new era is established – the era of incremental change. Here, future technological progress consist on further developing the dominant design through incremental innovation. The authors also point out that technological progress is cyclical, that is, the era of incremental change persists until a new technological discontinuity emerges.

Electric and autonomous vehicles can be understood through the logic of technological progress. Subscribing to Abernathy and Utterback (1978) three phases of innovation, we can identify the usages of the different consumers and the behaviours while using an electric vehicle. In addition, there are different standards, worldwide and at region and country levels. Incremental innovation is undertaken to improve EV batteries, where the objective is to obtain higher capacity and lighter batteries, elaborated with more efficient and sustainable materials. For now, the market only attracts early adopters. As for the dominant design of electric vehicles, there is not yet a clear consensus. There are still different types of electric vehicle technologies, notably the fully-electric vehicle (or battery electric vehicle –BEV) and hybrid electric vehicles (such as the plug-in-hybrid electric vehicle –PHEV). Uncertainty is also apparent in the charging mechanisms. Hence, we can deduce that autonomous vehicles are maturing in their fluid phase, and slowly switching to the transitional phase. As for autonomous vehicles, we observe that different designs are being adopted, and the usage and expectations of consumers are not yet converging to a single design. For instance, the usage of the car is unknown (i.e. people could work, watch movies, sleep, the vehicle can serve for delivery, for publicity purpose, among others). The business model is also unclear (i.e. AV proposed as a service or privately owned). Early stage standardization is starting to appear and there are few regulations in place for this type of technology. For the moment, consumer adoption is only undertaken by innovators, who are curious about the technology.

To give evidence of both electric and autonomous vehicles through the lenses of technological progress, we will develop their definition in depth, the state-of-the-art of both innovations, along with their promises and perils in the upcoming sections of this chapter.

1.3 Electric vehicles: a solution to achieve carbon neutrality

1.3.1 Definition

Electric vehicles (EVs) are vehicles that contain an electric motor, that is, they are powered using electricity. This differs to conventional vehicles, which use fossil fuels, like petrol or diesel, to propel an internal combustion engine. There are different types of electric vehicles: *Battery-electric vehicles (BEVs)* are powered only by an electric motor and power comes from electricity stored in an on-board battery that can be charged by plugging it to the gird. *Hybrid electric vehicles (HEVs)* are powered by an internal combustion engine and an electric motor. The electric motor of an HEV assists the conventional engine during tasks like acceleration. However, the battery of this type of vehicles cannot be charged directly from the grid, and instead, power comes from regenerative breaking. *Plug-in hybrid electric vehicles (PHEVs)*, like HEVs, combine an electric motor and an internal combustion engine, where both motors can function separately or together. The difference of PHEVs compared to HEVs is that their batteries can be charged from the grid. In addition, the combustion engine can assist the electric battery in cases of battery discharge or for higher power tasks. *Range extended electric vehicles (REEVs)* work similarly to HEVs, but their particularity is that the combustion engine is used to power the electric motor or charge the battery when its almost discharged. In these vehicles, the internal combustion engine has no role in powering the vehicle. *Fuel cell electric vehicles (FCEVs)*, also called hydrogen-powered vehicles, rely fully on electricity to power the vehicle. However, instead of a battery the energy is stored in fuel cells that generate energy by combining hydrogen compressed from the tank and oxygen in the air.

Electric vehicles differ in usage. For instance, light-duty electric vehicles can be acquired for private usage. Besides, EVs can belong to a fleet, which is normally managed by a company (e.g. Amazon, La Poste). Another type of usage is through the provision of a service, like shared vehicle services (e.g. Share Now, a shared vehicle concept developed by Daimler). Furthermore, different transport modes are turning to electrification. Aside from the four-wheeled light-duty vehicles, some examples are bikes, buses, vans, trucks, ships and airplanes. The solutions, usages and challenges differ between transport modes. In this thesis, we concentrate mostly on road light-duty electric vehicles.

Most EV types rely on charging points for their on-board batteries. Therefore, the deployment of electric vehicles is generally accompanied by the instalment of different types of charging stations. A common type of charging infrastructure is the private charging point, which is located at homes or businesses, and does not rely on any charging fees. Similarly, semi-public charging points are located in private places (i.e. shopping malls, workplace buildings), but are accessible to external users at a fee or are offered for just the price of the electricity at customers in the businesses. Finally, public charging points are accessible to all users at a fee.

Not only are there different types of charging points depending on their accessibility to the users, but also depending on the speed of power the vehicles receive. Chargers with 3-7 kW power are considered slow chargers, 22 kW as normal, 50 kW as fast, and 150 kW or more as ultra-fast. Users pay different fees and electricity prices depending on the speed preferred. The faster the speed, the higher the price. An overview of the fees for France are illustrated in table 3.2 in Chapter 3.

Although grid-connected charging points are the more widespread option to charge electric vehicles, there are two other, less popular options: battery swapping and wireless charging. Battery swapping consists of replacing a battery low on power with a fully charged one. However, a number of drawbacks have impeded battery swapping to be preferred over charging points. For instance, not all EV models supports battery swapping; there is no standard size or type of battery (EEA, 2016). Indeed, there is no promising business solution yet for this service. Better Place, the first proponent of battery swapping, went bankrupt in 2007 (Y. Chen, 2018). Wireless charging, also known as induction charging, consists of positioning an EV above a charging pad, which creates an electromagnetic field around it and receives electricity. Wireless charging can be done in two ways: static and dynamic. Static wireless charging charges the car while it is stationary (such as in a parking lot), whereas dynamic wireless charging charges the vehicle while it is in motion. For such charging option to become a reality, infrastructure changes are required. Short segments of roads must be constructed or renovated to install the wires underneath the roads that will allow for wireless charging. At the moment, wireless charging is working on several testing locations around the world (EEA, 2016). There is not yet a commercial solution for this type of service.

All in all, electric vehicles depend on different elements, or components, for the final product to fully work. Therefore, we can consider that electric vehicles are built around an innovation ecosystem. An innovation ecosystem is defined by a group of firms producing components that result in a focal offer. These components are interdependent among each other to offer a fully functional product (Hannah & Eisenhardt, 2018). We adapt the definition of the electric vehicle ecosystem proposed by Y. Chen (2018). The battery electric vehicle (i.e. the focal innovation) as a product is made possible by a set of components: the battery, the electric motor, the on-board charger and plug, and the charging infrastructure (public and private). Interdependence among components is visible in the ecosystem, especially when it comes to offering energy services to the grid (Codani, Petit, & Perez, 2015; Lerch, Kley, & Dallinger, 2011) Different companies coming from various industries draw on their own capabilities to produce a component of the EV. For instance, companies like Ganfeng Lithium, Amperex Technology and Panasonic manufacture lithium-ion batteries, automakers like Tesla, Renault or BMW manufacture the electric motors, while companies like ChargePoint, EVBox, General Electric, BP, Shell, or even automakers like Tesla and Renault install the charging stations network.

1.3.2 The history of electric vehicles

The first electric vehicles appeared in the 19th century as a series of breakthroughs around the world. An early type of electric motor and electric vehicle was developed in 1828 by Hungarian Ányos Jedlik. Alongside, the first crude electric carriage was invented by Scottish inventor

Robert Anderson. Likewise, a small-scale electric car, powered by non-rechargeable primary cells was developed by Dutch Professor Sibrandus Stratingh of Groningen, and his assistant Christopher Becker from Germany. Other innovations at the time allowed for the electric vehicle to materialize. For instance, the DC electric motor was invented in 1834 by American Thomas Davenport, and a practical rechargeable battery — the lead-acid battery for electric cars — was developed in 1881 by French scientists Gaston Plante and Camille Faure. Both in the U.S. and Europe there was interest in these type of vehicles, with France and Great Britain being the first countries to support their development (Guarnieri, 2012).

Electric vehicles, and motor vehicles in general, were promising since they helped solving the unsustainable mode of transport at the time: the horse. Cities were becoming more populated and the economy was getting more prosperous. Using horses in a densely populated city caused problems like congestion, the accumulation of horse manure on the streets, a strong smell from manure, a higher likelihood to propagate infectious diseases, and a high dependence to the well-being and nourishment of horses, which were frequently overworked and required food and farmland. The entrance of the steam locomotive aggravated the negative externalities of transportation at the time. With locomotives, intercity transport was achievable, increasing the demand for transport of goods and people and causing more congestion.

"Horseless carriages", as they used to call motor vehicles, were seen as a solution to mitigate horse transport related problems. Electric vehicles, specially, were quiet, easy to drive and did not exhaust pollutants or smell of any sort. Given that batteries had a small capacity, EVs were targeted to short trips in a city, fitting the expectations at the time, due to the poor intercity road conditions. The entrance of the electric vehicle was also accompanied with the widening of electrification in the 1910s, which increased their popularity. In the meantime, internal combustion engine vehicles (ICEVs) entered the market as a less attractive solution. Contrary to EVs, gasoline-powered vehicles required more effort to drive as the engine started with a hand crank and changing gears was difficult. Besides, they emitted more noise and emitted a visible and strong-smelling pollutant. While, at the beginning of the 20th century, motor vehicles had still not replaced the horse as the primary mode of transportation, problems related to horse transportation continued exacerbating, making both EVs and ICEVs a necessary solution. Electric vehicles where highly popular among consumers, especially in Continental Europe and Great Britain during World War I. In the US, over 300 manufacturers produced an electric vehicle up to 1942. For instance, Thomas Edison believed that electric vehicles, compared to ICEVs, were the better technology, and even partnered with Ford to develop a low-cost electric vehicle technology (Matulka, 2014).

Despite the high momentum of electric vehicles, it was ICEVs that established in the market. Several factors led to the fall of EVs compared to ICEVs. Firstly, Ford's mass-produced Model T, an ICEV, reduced the cost of owning a vehicle and made it accessible to the general public. On the contrary, EVs were expensive and targeted to wealthier populations. By 1912, an ICEV was sold for $650, compared to $1,750 for an EV. In addition, ICEVs became easier to use, as the electric starter replaced the manual starter. Advancements in road infrastructure made it possible to connect different cities by car, and gasoline stations network started to develop in roads, which made gasoline-cars more accessible to drive long-distances. Electricity, on the contrary, was not as present outside cities, which made it difficult to travel long distances. On top of that, the discovery of Texas crude oil lead to lower gasoline prices, which made ICEVs even more appealing (Matulka, 2014).

Fast forward to 1973, the oil crisis triggered the interest of affected nations in lowering the dependency on foreign oil. Countries evaluated alternative ways of transportation as a possibility to reduce oil dependency, among which the development of electric vehicles. For instance, the U.S. congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976, authorizing the Energy Department to launch R&D projects related to electric and hybrid vehicles. Car manufacturers on their own also got interested in developing alternative fuelled cars, among which the electric car. For instance, General Motors developed an electric version of its gasoline-powered Chevrolet Corvair, the Electrovair. However, the advancements in EVs were still not enough to replace ICEVs. Electric vehicles during this time had limited performance, usually topping at speeds of 72 km per hour, and had a driving range of 64 km (Matulka, 2014).

Interest for alternative fuelled vehicles increased again with environmental concerns. For instance, in the U.S., the 1990 Clean Air Amendment and the 1992 Energy Policy Act proposed a framework and provided tax incentives for alternative fuel vehicles. In Europe, the Euro emissions regulations from 1992 imposed emission restrictions for passenger and later commercial vehicles. Although there was not much interest from the consumer side, scientists and engineers were interested in improving EV technology.

At the beginning of the 21st century, multiple factors gave visibility again to electric vehicles. One defining factor was the release of the Toyota Prius, the world's first mass-marketed electric vehicle, in Japan in 1997 and in the world in the 2000's. The entrance of Tesla Motors in 2004 and the development of the Tesla Roadster allowed industry players to realize the market potential of EVs. The Roadster was the fist serial production BEV to use lithium-ion battery cells. Autonomy was also highly improved, driving more than 320 km per charge. Subsequently, the Chevy Volt entered the market as the first commercial plug-in hybrid and the Nissan Leaf was the first modern, family-format EV produced by a major automaker. Since then, most of the major manufacturer have started to produce at least one EV model. Efforts from the private side were also accompanied by the encouragement of governments to switch to electric vehicle technologies (Matulka, 2014).

1.3.3 State-of-the-art of electric vehicles

Electric vehicles are rapidly increasing in numbers. In the 2010-2020 period, they passed from not having any market share to represent 1% of the world's car stock, corresponding to 10 million electric vehicles on the road. Even considering the pandemic's negative shock of 16% in global car sales, worldwide electric vehicle registrations increased by 41% in 2020. Worldwide electric car sales corresponded to 4.6% of total car sales. In 2020, around 3 million new electric vehicles were registered worldwide. Europe, for the first time, led the list, with 1.4 million registrations. In second and third place, China and the U.S. registered 1.2 million and 295,000 new electric vehicles (IEA, 2021a). Both BEV and PHEV markets are expanding in all regions in the world. Figure 1.1 illustrates the BEV and PHEV stock for selected regions from 2015-2020.

Similarly, the infrastructure needed to charge EVs is expanding. In 2019, there were about 7.3 million chargers, of which about 6.5 million were private (located both in residential and

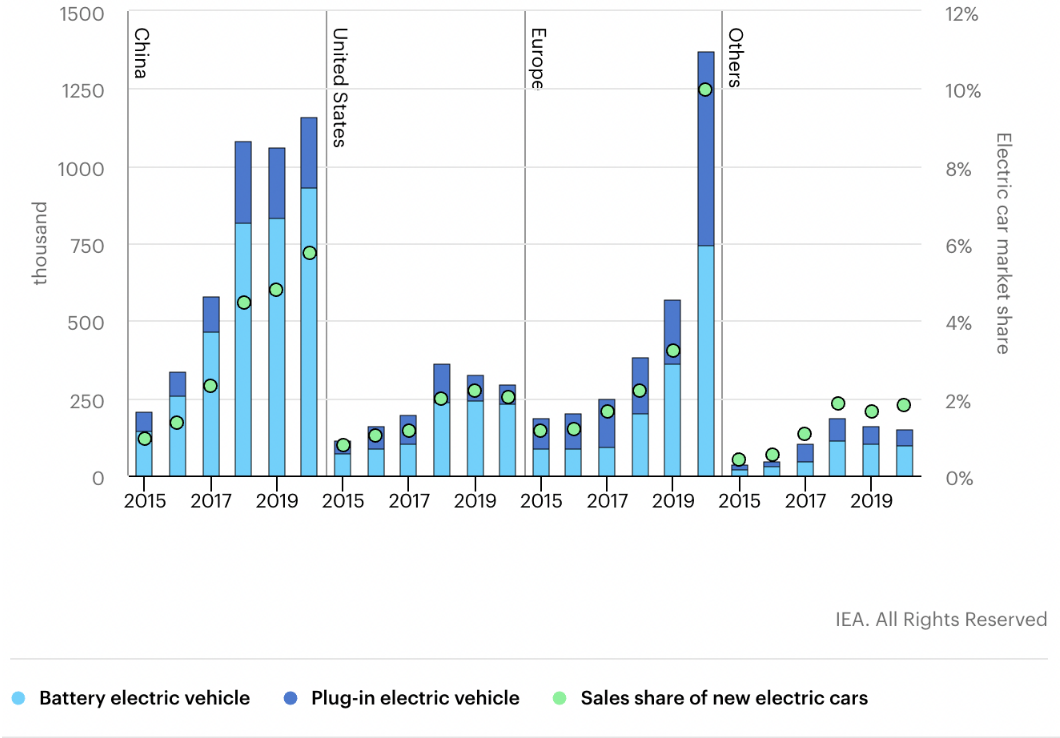

Figure 1.1: BEV and PHEV car registrations and market share, 2015-2020 (IEA, 2021a)

commercial buildings). In 2020, public chargers accounted for 1.3 million, of which 30% corresponded to fast and ultrafast chargers (charging power above 22 kW). China is the country leading the installation of public chargers. The country's stock of chargers represents more than half the world's stock. Europe is second at deploying charging stations, with a higher rate of roll-out for fast and ultrafast chargers. As for the ratio of public chargers per EV stock, The Republic of Korea leads the list, with 0.47 chargers per EV. In the European Union, the Netherlands is first, with 0.23 chargers per EV, then Italy, with 0.13 chargers per EV, and then France with 0.10 chargers per EV (IEA, 2021a).

EVs' driving range has also improved in recent years. The average driving range for a new battery electric vehicle in 2015 was 200 km. In 2020, this value increased to 350 km. For a PHEV, this value has been stable at 50 km for the past years. As for battery technology, efforts have been placed in reducing the cost of batteries. For instance, the cost of lithium-ion batteries decreased from $1,100 per kilowatt-hour in 2010 to $156 per kilowatt-hour in 2019. Finding alternative materials to construct batteries is another angle of development. For exam-

Figure 1.2: Stock of >22 kW (left graph) and <22 kW (right graph) public electric light duty vehicles chargers, 2015-2020 (IEA, 2021a)

ple, research is concentrated in making "solid-state" batteries[1], which allows for a significant reduction in overall battery size while maintaining energy storage capacity, resulting in a better energy density (Stauffer, 2021).

Car manufacturers are on board with vehicle electrification. In 2020, about 370 electric car models were available, representing an increase of 19% from 2019. The biggest increase in number of models for the past year was in Europe, though China holds the first place in the overall number of models available. Regarding automakers' targets, 18 out of 20 of the world's top vehicle manufacturers, representing 90% of new car registrations in 2020, have strategies to scale up EV production and increase their EV portfolio (IEA, 2021a). For instance, Stellantis plans to invest more than 30 billion euros by 2025 in electrification and software, and expects to sell over 70% of low emission vehicles in europe and over 40% in the U.S. by 2030 (Stellantis, 2021). Similarly, BMW plans to raise EV deliveries to at least 30% in 2025, and to at least 50% in 2030. By 2030, BMW plans to offer only all-electric vehicles to its MINI and Rolls-Royce customers (BMW, 2022).

Countries have also set ambitious targets regarding transport emissions reduction, and electric vehicles are part of that strategy. For instance, Europe has set itself ambitious targets, such as achieving climate neutrality by 2050, disentangling economic growth from resource use, while ensuring opportunities for everyone and supporting vulnerable population in the transition. Transportation is widely involved in reaching the targets: Emission reduction targets by

[1]A solid-state battery is a battery technology that uses solid electrodes and a solid electrolyte to regulate lithium-ion or lithium polymer batteries, instead of liquid or polymer gel electrolytes

2030 are 55% for cars and 50% for vans. By 2035, the target is to reach zero emissions from new cars. In addition to the targets for current cars, the European Commission encourages the growth of low and zero emission vehicle markets, and their required infrastructure, and supports the deployment of automated mobility at a large scale. Similarly, under the Biden administration, the United States aims at reducing Greenhouse gas (GHG) emissions by 50-52% from 2005 levels in 2030, and encourages electric vehicle adoption to attain these targets. Hence, countries have put great interest in promoting policies that generate incentives to the purchase of electric cars and the installation of charging infrastructure.

Figure 1.3 compiles zero-emission policies in place by the end of 2020 for selected countries and regions. There are four main policy categories: regulations on vehicles, incentives on vehicles, regulation on chargers and incentives on chargers. As for the regulations on vehicles, many countries have put in place zero emission vehicle (ZEV) regulations such as mandates on manufacturers to accelerate the rate of deployment. For instance, The California mandate requires manufacturers to meet credit-based requirements, not direct market-share targets. Affected manufacturers are subject to increasingly stringent ZEV percentage credit requirements of 22% in 2025. Credits are awarded upon the delivery of a ZEV for sale in California. While the percentage credit requirement remains the same for both intermediate and large manufacturers, the two are treated differently in the types of vehicles that can be used to meet the credit requirements. Large-volume manufacturers are required to fulfill a certain percentage of their ZEV credit requirements through pure ZEVs, or BEVs and FCEVs, also known as the "minimum floor volume". In China, the New Energy Vehicle (NEV) mandate sets annual NEV credit targets at 10% of the conventional passenger vehicle market in 2019 and 12% in 2020. Each NEV is assigned a specific number of credits ranging from one to six, depending on metrics including electric range, energy efficiency, and rated power of fuel cell systems. These NEV credit targets apply to all auto companies with annual production or import volume of at least 30,000 conventional passenger cars. Other countries and regions, like Japan and the European Union, do not have a true mandate for ZEVs. Instead, they rely on fuel economy standards. In the European Union, manufacturers can attain voluntary ZEV quotas and in return claim compliance offsets against the proposed post-2021 corporate average standards. Manufacturers that exceed these voluntary targets are eligible to receive specified levels of relaxation on their standards. Under the prevailing EU corporate average CO2 standards, fleetwide emissions from new passenger cars are required to fall to 95 g/km by 2021. For the post-2021 period, the European Commission has proposed to further tighten the standards with a 15% reduction from the 2021 limit by 2025 and a 37.5% reduction by 2030.

Incentives are also used to boost EV adoption. Some of the incentives targeted to vehicles are subsidies, registration tax rebates, parking-fee and toll exemptions, among others. For instance, EV adopters in France can benefit from two main different bonuses: the "Ecological Bonus", which varies depending on the purchase price of the vehicle and on the CO2 emissions level of the vehicle, and the "conversion bonus", a subsidy for the purchase of second hand or new BEVs and PHEVs when scrapping a diesel car (older than 2011) or gasoline car (older than 2006).For example, private individuals can get €7,000 and businesses can obtain €5,000 of ecological bonus for a car/van emitting 20g CO2/km or less for a vehicle under €45,000, and €3,000 for a car between €45,000 and €60,000. The conversion bonus for individuals with an income of less than €13,489 is up to €5,000. Other fiscal incentives are targeted to the installment of charging infrastructure. For instance, in France, the EV Infrastructure Charging Program ADVENIR, was launched in 2016 to help finance private charging infrastructure for company fleets and in apartment buildings. As part of its renewal for the period 2020 - 2023, the ADVENIR program has a budget of 100 million euros with the objective of financing more than 45,000 new charging points by the end of 2023. The ADVENIR premium depends on the place of installation (condominium, private parking, roads, etc.), the power and use of the charging station (private, public).

1.4 Autonomous vehicles: a solution to achieve security, accessibility and land-efficiency

1.4.1 Definition

Autonomous vehicles are vehicles capable to drive with little or no human input. Some controversy has emerged with the terms used to define vehicles that can drive by themselves. For instance, the terms autopilot, drivepilot or derivatives, might give overconfidence to drivers in the vehicle's system. That is, the terms might confuse drivers in believing the vehicle needs no

Figure 1.3: Zero-emission light-duty vehicle policies and incentives in selected countries by 2020 (IEA, 2020)

		Canada	China	European Union	India	Japan	United States
Regulations vehicles	ZEV mandate	**British Columbia**: 10% ZEV sales by 2025, 30% by 2030 and 100% by 2040. **Québec**: 9.5% EV credits in 2020, 22% in 2025.	**New Energy Vehicle dual credit system**: 10-12% EV credits in 2019-2020 and 14-18% in 2021-2023.				**California:** 22% EV credits by 2025. **Other states:** Varied between ten states.
	Fuel economy standards (most recent for cars)	114 g CO_2/km or 5.4 L/100 km*** (2021, CAFE)	117 g CO_2/km or 5.0 L/100 km (2020, NEDC)	95 g CO_2/km or 4.1 L/100 km (2021, petrol, NEDC)	134 g CO_2/km or 5.2 L/100 km (2022, NEDC)	132 g CO_2/km or 5.7 L/100 km (2020, WLTP Japan)	114 g CO_2/km or 5.4 L/100 km*** (2021, CAFE)
Incentives vehicles	Fiscal incentives	✓	✓	✓	✓	✓	✓
Regulations chargers**	Hardware standards.	✓	✓	✓	✓	✓	✓
	Building regulations.	✓*	✓*	✓	✓		✓*
Incentives chargers	Fiscal incentives	✓	✓	✓	✓	✓	✓ *

* Indicates that it is only implemented at state/provincial/local level. ** All countries/regions in the table have developed basic standards for electric vehicle supply equipment (EVSE). China, European Union and India mandate specific minimum standards, while Canada, Japan and United States do not. *** Historically, Canada and the United States have aligned emission standards for on-road light-duty vehicles. In April 2020 the United States adopted a final rule to reduce the annual stringency conditions for the 2021-2026 model years. Soon after, Canada finalised its mid-term evaluation of the Passenger Automobile and Light Truck GHG Emissions regulation, indicating a potential separation from the US ruling, pending further consultation. ✓ Indicates that the policy is set at national level. Notes: g CO2 /km = grammes of carbon dioxide per kilometre; L/100 km = litres per 100 kilometres; CAFE= Corporate Average Fuel Economy test cycle used in the United States and Canada fuel economy and GHG emissions tests; NEDC = New European Driving Cycle; WLTP= Worldwide Harmonized Light Vehicle Test Procedure; WLTP Japan = WLTP adjusted for slower driving conditions in Japan. Building regulations imply an obligation to install chargers in new construction and renovations. Charger incentives include direct investment and purchase incentives for public and private charging.

human intervention, while it does need an alert human driver to be involved in the task. Organizations like the Association of British Insurers have expressed their concerns with both the terms autonomous and autopilot, because of the confusion it may cause in users. However, both autonomous and automated vehicles are used to express the concept in the literature.

To mitigate the misunderstanding relating the technology's meaning, standardization bodies have attempted to well-define autonomous driving. The most well-known and broadly accepted taxonomy was developed by the Society of Automotive engineers (SAE). The SAE proposes a definition and categorization of vehicle automation, which was then adopted by the the U.S. Department of Transport (National Highway Traffic Safety Administration-NHTSA), and which inspired EU regulation. The SAE taxonomy defines driving automation using six levels, where the higher the level, the higher the role of the driving automation system with respect to the human driver. The levels of driving automation are as follows (NHTSA, 2022; SAE, 2021):

- **Level 0**, or *momentary driver assistance*. Human drivers carry out most of the functions, while the vehicle provides temporary driving assistance, such as warnings and alerts, or emergency safety interventions.

- **Level 1**, or *driver assistance*. Human drivers carry out most of the functions, while the vehicle provide either steering or brake/acceleration.

- **Level 2**, or *additional assistance*. Human drivers carry out most of the functions, and the vehicle assist on both steering and brake/acceleration.
- **Level 3**, or *conditional automation*. The vehicle's system drives under certain conditions, but the human driver should be prepared to take control when necessary.
- **Level 4**, or *high automation*. The vehicle system drives and does not need human intervention, under a defined condition.
- **Level 5**, or *full automation*. Vehicles can drive under all conditions with no need for human intervention.

The EU Regulation 2019/2144 regarding motor vehicles simplifies the definition of autonomous driving into two terms: An 'automated vehicle' means "a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required". A 'fully automated vehicle' means "a motor vehicle that has been designed and constructed to move autonomously without any driver supervision".

To function, autonomous vehicles require different components that allow them to drive and make on-road decisions with little to no human intervention. For instance, LiDar consists on infrared sensors that detect incoming objects by a 3D rendering of the vehicle's surroundings, and captures a 360° field of vision. Besides, cameras capture images of the surroundings, and gathers information like colors and fonts, that are useful to detect information on traffic lights, road signs and lanes. Other components are radars, localization technology, Vehicle-to-everything, Software and OS, cloud, teleoperation and cybersecurity. A more detailed explanation of the different components can be found in chapter 2.

The different components are organized to ensure that the entire system satisfies performance, interoperability, suitability and reliability. This is referred to as "software architecture". That is, without one of these components, achieving full autonomous driving is hardly possible, as they are all fundamental building bricks of the AV system. As a result, autonomous vehicles can be thought of as part of an innovation ecosystem. A group of enterprises producing components that culminate in a central offer defines an innovation ecosystem. To provide a completely functional product, these components are depending on one another (Hannah & Eisenhardt, 2018).

Autonomous vehicles can have different applications. For example, AVs can provide transportation services through robo-taxi, ride-hailing, ride-sharing or autonomous shuttle services. In addition, they can be coupled with public transport systems and make part of a Mobility as a service (MaaS) offer. AVs can also provide last-mile transport services by facilitating the delivery of goods. Furthermore, autonomous vehicles can operate as single agents or in platoons[2], which is particularly the case for autonomous trucks.

1.4.2 The history of autonomous vehicles

Autonomous vehicle experiments have been developed since the 1920s. The first one was undertaken in 1925 by the company Houdina Radio Control. A vehicle, called the "Phantom Auto", operated by a remote control, drove along New York City roads, even through a traffic jam. However, the Phantom Auto did not mark a big leap in AV development. Years later, at the Futurama section in the 1939 New York World's Fair, Norman Bel Geddes and General Motors exhibited the vision of future cities, where vehicles had zero human intervention and circulated along automated highway systems, propelled electromagnetically by wires in the pavement. This vision required an enabling infrastructure. Likewise did the concept by Bel Geddes, RCA (Radio Corporation of America), who in 1953 developed a system with a vehicle controlled by wires. This system was later tested on a public highway in the State of Nebraska, and in Princeton, New Jersey. In the UK, similar tests were undertaken by the UK Transport and Road Research Laboratory, using a Citroen DS. The vehicle drove through a track at 130 km/h, enabled by magnetic wires embedded on the road. Cost-benefit analyses of this type of technology in Britain suggested that costs would be repaid by the end of the century, increase the road capacity by at least 50% and prevent around 40% of the accidents. However, the experiments were not pursued due to funding withdrawal by the mid-1970s. By then, the computer age switched the priorities from the design of automated highway systems to the development

[2]Platooning is the integration of two or more vehicles in a convoy through the use of connectivity technology and automated driving support systems. When connected for specific parts of a route, it allows the cars to maintain a predefined, close distance between them and react to changes in the movement of the lead vehicle with little to no intervention from the drivers (European Parliament, 2019).

of autonomous cars. In 1977, a team at Japan's Tsukuba Mechanical Engineering Laboratory developed a vehicle equipped with two cameras and an analog computer that was capable of travelling up to 19 mph, but required a rail for guidance. In 1979, scientists from Stanford University demonstrated a cart that successfully navigated a room filled with chairs with no human intervention (Nguyen, 2016).

During the 1980's and 1990's, university research centers, sometimes in cooperation with automotive companies, began the development of the main technologies needed for automation. For instance, a research team led by engineer Ernst Dickmanns at the Bundeswehr University in Germany developed a vision-guided Mercedes Benz vehicle able to navigate at 100 km/h without traffic (J. Anderson et al., 2016). This test was the first to operate autonomously without any infrastructure improvements. The developments by Dickmanns and his team inspired EUREKA, an intergovernmental organization that fosters R&D funding and coordination in Europe, to conduct the "Prometheus Project", which took place from 1987 to 1995 and received a funding of €749,000,000, to advance the technologies required for autonomous vehicles. Two autonomous cars, the VaMP and VITA-2 of Daimler-Benz and Ernst Dickmanns team, were the result of the Prometheus Project. These vehicles could drive up to 80 mph in real traffic. In the U.S., Carnegie Mellon University developed, between the 1980s to early 2000s, a series of vehicles called the NavLab (from 1 to 11). Carnegie Mellon University was the pioneer on the use of neural networks to steer and control AVs (Nguyen, 2016). In South Korea, in 1993 professor Han Min-Hong from Korea University developed an autonomous vehicle capable of driving 17 kmh in Seoul. A different vehicle was tested two years later on Gyeongbu Highway, driving from Seoul to Busan. However, government funding allocated to Korea University was cut for this project (AFP, 2021).

Legislative efforts were also conducted at the time in the U.S. with the ISTEA Transportation Authorization bill passed by the Congress in 1991. The bill instructed the United States Department of Transport (USDOT) to demonstrate automated vehicles by 1997. The bill's approval spurred research and development around automated systems in collaboration between public, private and academic parties. The results of the collaborations were showcased in a demo, which took place on I-15 in San Diego, California. The demo included 20 automated vehicles (cars, buses trucks), platooning for segregated traffic operations and solo vehicles for mixed traffic operations. Even other automakers, like Honda and Toyota, participated in this demonstration. The final objective of the USDOT program was to launch a commercial autonomous system. However, the initiative was cancelled in the late 90's due to its tighter research budget.

By the end of the 1990s, the "ParkShuttle", an automated people mover[3] developed in the Netherlands passed the experimentation phases at Schiphol Airport and business park Rivium and began to be used in 2009. The Parkshuttle can be considered the first autonomous vehicle, since it was the first to carry people from the general public.

From 2003 to 2007, the U.S. Defense Advanced Research Projects Agency (DARPA) launched three "grand challenges" to encourage the development of autonomous vehicles that can avoid obstacles and drive along difficult terrain types. The first grand challenge was held in 2004 along a 150-mile course for a prize of a $1 million. However, no vehicle could complete the course. For the 2005 grand challenge, vehicles again competed to complete a 150-mile course for a prize of $2 million. Five teams successfully completed it. The fastest team completed the course under seven hours, and the next three teams finished within the next 35 minutes. The last challenge, called the "Urban Challenge", was held in 2007, and consisted on racing through a 60-mile urban course. The condition for this race was to respect traffic rules and drive alongside other autonomous and human-driven vehicles. This time, six teams completed the course, and three finished within 4.5 hours, including penalties attributed to the violation of traffic and safety rules. This challenge was crucial to develop sensors and algorithms that help with detection and reaction to different objects of the driving environment. Some partnerships between universities/research labs and automotive manufacturers, with the aim to further develop the AV technologies, originated from the DARPA challenges, such as the partnership between General Motors and Carnegie Mellon University, and between Volkswagen and Stanford University (J. Anderson et al., 2016).

In 2009, not long after the DARPA challenge concluded, Alphabet - the parent company of Google - started developing an autonomous and full-electric car for commercial purposes, the "Google Car", through its subsidiary Waymo (J. Anderson et al., 2016). Since then, Alpha-

[3]An automated people mover is a type of small scale automated guideway transit system. The term is generally used only to describe systems serving relatively small areas such as airports, downtown districts or theme parks.

bet has launched many tests for its vehicle fleet and initiated advertising its technology usages. The subsequent decade, many of the major car manufacturers, like Toyota, BMW, Audi, Ford, Volkswagen and Nissan, announced plans to develop autonomous vehicles. In 2010, the University of Parma laboratory, VisLab, launched the VisLab Intercontinental Autonomous Challenge, which consisted of a 9,900 mile (15,900 km) drive from Parma, Italy, to Shanghai, China, to arrive at the Expo 2010 Shanghai. Four vehicles completed the challenge in 100 days (Broggi et al., 2012). In the same year, the Institute of Control Engineering of the Technische Universität Braunschweig, Germany, demonstrated the first autonomous vehicle on public streets in Germany. The vehicle became the first to be licensed for autonomous driving on the streets and highways in Germany. In 2014, Navia's shuttle was the first vehicle to be available for commercial sale. The shuttle was limited to 12.5 miles per hour (20.1 km/h) and had seats for up to eight people. The same year, Alphabet announced it would display 100 AV prototypes, and Tesla announced it would include the necessary hardware for automation in its vehicles, called the Autopilot. Tesla's Model S was capable of recognizing images and could actuate (e.g. steer, brake, and control speed limit). In 2016, Tesla announces that its vehicles are built with the technology that enables full self-driving (corresponding to level 5 autonomy, as described by the SAE), and promised to enable full autonomy by 2017, a promise that up to now has not been accomplished. The world's first fully electric autonomous bus open to the public was launched in 2018 in Neuhausen am Rheinfall, Switzerland (CNN, 2018).

The 2010s was also marked by an interest in setting regulations and standards relating to autonomous vehicle technologies. Nevada, for instance, passed a law in 2011 concerning the AV testing and operation. This law required a person behind the wheel and another one in the passenger's seat during tests. It also was the first in issuing a license plate for autonomous vehicles. A Toyota Prius operating with Google's software system was the first vehicle to obtain this license. The States of Florida and California followed Nevada in approving tests for AVs. Similarly, the UK allowed for testing of the LUTZ Pathfinder driverless pod in Milton Keynes in 2015. In the case of France, testing was allowed in 2016. Cities like Paris and Toulouse subsequently engaged in tests with EasyMile, a driverless shuttle company. As for vehicle standards, in 2014 the SAE published the J3016 Standard, titled "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems", which provided a detailed definition and classification for autonomous vehicles in six levels (SAE, 2021).

Along with the advancements in the technology came also the tragedies associated to autonomous vehicles. The first fatal accident occurred in 2016 in Williston, Florida, when a Tesla Model S vehicle was driving in autopilot mode and crashed with a large 18-wheel tractor-trailer (Yadron & Tynan, 2016). In 2018, the first fatal accident involving an self-driving Uber vehicle and a pedestrian occurred in Arizona (Levin & Wong, 2018).

1.4.3 State-of-the-art of autonomous vehicles

As mentioned in the previous section, autonomous vehicles had a high level of expectation and promise at the start of 2010. Multiple automakers and companies from other industries worked on the development of AV systems and their components. By the end of the decade, accidents associated to autonomous vehicles and unfulfilled promises changed the prospects for AVs to a less optimistic view. Even the former CEO of Alphabet's Waymo, John Krafcik, a big advocate of autonomous vehicles, expressed his concerns with the development of AV technology. In an interview with the Financial Times, he said: "It's an extraordinary grind, I would say it's a bigger challenge than launching a rocket and putting it in orbit around the Earth...because it has to be done safely over and over and over again." (McGee, 2021).

It is tacitly understood among AV stakeholders that plans to deploy the technology have to extend to a further date. For instance, Waymo announced in March 2018 that up to 20,000 autonomous electric Jaguars would be built in the next two years of production. The vehicles would serve 1 million trips per day through Waymo's driverless service. These 20,000 AVs would have added to up to 62,000 Chrysler autonomous minivans, as announced in May 2018. Two years passed and Waymo's official fleet size has still not reached the target, and it remains at 600 vehicles as of 2021 (McGee, 2021). Uber, heavily impacted by the fatal accident with one of its autonomous vehicles in 2018, decided to abandon its 5 years progress, and sell the autonomous vehicle division to Aurora, a startup developing AV technology. Still, Uber secured participation in Aurora, by investing $400 million in return for a 26% stake in the company, plus board presence (Kollewe, 2020).

Much of the decay of optimism is due to the underestimation of the technological challenges that the autonomous vehicle could face when driving. For instance, the capability to detect and classify objects in a very accurate manner, especially in unlikely situations or environments, is a challenging task that requires a large set of tests and data for the vehicle to understand all the possible driving scenarios.

The COVID-19 pandemic also contributed to slowing down plans and expectations for autonomous driving deployment. Transportation was one of the most affected sectors by the pandemic. In addition, there is uncertainty at which point users' habits regarding shared-rides will change in the long-term, which could represent a drawback for autonomous car services that rely on car sharing. For instance, Ford announced a delay of their autonomous vehicle service, which was expected for 2021, to 2022.

Another reason for the more realistic viewpoint towards AVs is that many regulations in the world are still not implemented. Currently there are two regulations in place for AVs. In Japan, the "Road Traffic Act" and "Road Transport Vehicle Act" were amended in 2019 and came into effect in 2020. These laws allowed Level 3 self driving cars on public roads, and consider the necessary features to ensure autonomous driving safety for level 3 vehicles. Both laws are being revised to include level 4 automation (Imai, 2019). In the European Union, Regulation 2019/2144 specifies the safety requirements for motor vehicles and their trailers systems, components and separate technical units intended for such vehicles (European Parliament, 2019). The regulation introduces advanced safety systems for vehicles such as intelligent speed assistance, alcohol interlock installation facilitation, driver drowsiness and attention warning systems, advanced driver distraction warning systems, emergency stop signals, reversing detection systems, event data recorders, and accurate tyre pressure monitoring. The regulation comes into effect in 2022. In Germany, the Federal Act Amending the Road Traffic Act and the Compulsory Insurance Act came into effect. The act allows Level 4 vehicles in specific operating areas on public roads (Bundesministerium der Justiz, 2021).

Other countries and regions in the world have not yet implemented regulations on autonomous vehicles. In the UK, a proposal for a new law is being developed after a public consultation was concluded in 2020. The law seeks to allow self-driving automated lane keeping systems (ALKS) up to 37 mph (Webster, 2021). In the U.S., there is no Federal regulation in place. Nevertheless, in 2016 the US National Economic Council and US Department of Transportation (USDOT) released the Federal Automated Vehicles Policy, which sets standards that describe how automated vehicles should react if their technology fails, how to protect passenger privacy, and how riders should be protected in the event of an accident (NHTSA, 2016).

1.5 The promise of electric and autonomous mobility

1.5.1 The promise of electric vehicles

Transport is a sector full of negative externalities. One of them is the emission of Greenhouse gases (GHG). Greenhouse gases, such as water vapor (H2O), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and ozone (O3), trap the heat in the atmosphere, making the planet warmer (global warming). Consequences of global warming are massive, for instance, the accelerated melting of world's ice, the acidification of oceans, threatened ecosystems, climate poverty and water scarcity. The Intergovernmental Panel on Climate Change (IPCC) advises to limit average global temperature rise to 1.5°C above pre-industrial levels in order to avoid irreversible dangerous consequences to our planet. At a rise above 1.5°C, entire ecosystems can be wiped out of the earth, such as the ones dependant on coral reefs. The transport sector is one of the most emitting economic sectors. In the U.S., transportation accounted for 29% of 2019 total GHG emissions, making it the most emitting sector (U.S. EPA, 2018). Similarly, EU transportation emissions corresponded to 24.6% of total emissions in 2018(Eurostat, 2014). In addition, it is the only sector to have increased the emissions level in recent decades in the EU. Road transport, specifically, is responsible for the highest share of total transport emissions (around 72%, in the EU in 2019), since it is a sector heavily reliant on oil products (EEA, 2021)[4].

Furthermore, transportation is responsible for a high share of world's air pollution, which

[4]A 2008 study undertaken by the TU Dresden for each of the EU-27 countries reports that climate change costs range from €5.832-20.369 million in France, and €9.121-31.856 million in Germany. The study measures "climate change costs" as the avoidance costs to reduce the risk of climate change. A more recent study, with 2017 data, estimates that climate change costs are of €0.011 per passenger kilometers (pkm) (Gössling, Choi, Dekker, & Metzler, 2019).

causes great damage to people's health (WHO, n.d.-a)[5]. Gasoline-powered vehicles exhaust polluting gases to the air like nitrogen oxides (NOx), particulate matter (PM), sulfur dioxide (SO2) and volatile organic compound (VOC) as a residue from fuel combustion. Studies point out that there is no safe level of air pollution (Hoffmann et al., 2020). Indeed, almost all of the global population (99%) are exposed to air pollution levels that could increase the risk for diseases. Some of the most common diseases aggravated by air pollution are respiratory and cardiovascular diseases, stroke and lung cancer (WHO, n.d.-b). Although emissions of air pollutants have decreased from the levels of the 1990s, emissions from road vehicles are still the leading source of NOx and the third largest source of PM2.5[6].

Transport is also responsible for the highest levels of noise pollution in the EU, specially from road traffic[7]. According to the World Health Organization, noise from road traffic is the second most harmful environmental stress causing factor in Europe. Some of the health consequences of noise pollution can be cardiovascular disease, premature death, sleep disturbance and hypertension. Aside from health consequences, noise pollution can impact other factors like productivity. Around 100 million people in the 33 member countries of the European Environmental Agency (EEA) are exposed to levels of noise pollution that exceed the EU threshold of 55 decibels (dB) and 50 dB for daily and nightly exposure, respectively (EEA, 2017). In the U.S., daily noise pollution levels are also significant. According to the U.S. Bureau of Transport Statistics (BTS), 6.5% Americans are exposed, on average, to 50-54 dB daily, levels comparable to the noise of a conversation. Moreover, 3.5% are exposed to 55-59 dB, levels comparable to the noise at a restaurant, while 2.3% are exposed to 60-69 dB levels of aviation and road noise pollution, levels comparable to the noise of a vacuum cleaner (BTS, 2020).

Electric vehicles, especially battery electric vehicles, have the potential to reduce the negative externalities mentioned above. Regarding GHG emissions, EVs' impact varies according

[5]The costs of transport-related air pollution are non-negligible. A study observing 432 European cities estimated that air pollution from transportation costs an average European city resident €1,276 in 2018 (de Bruyn & de Vries, 2020).

[6]Particulate matter are fine particles of solid and liquid matter suspended in the air. PM10 refers to particulate matter with a diameter of 10 micrometers or less. PM2.5 refers to particulate matter with a diameter of 2.5 micrometers or less.

[7]Costs of noise pollution are estimated to reach €0.007 per pkm, corresponding to the 2017 cost-benefit analysis by Gössling et al. (2019). In France, they can attain €1.093 million per year, and in Germany €621 million per year.

to multiple factors, such as the size of the vehicle, the mileage, the electricity mix, and the vehicle's life cycle stage. At the production stage, BEVs emit 1.3-2 times more GHG than conventional vehicles (Ellingsen, Singh, & Strømman, 2016; Kim et al., 2016). At the usage stage, EV's impact largely depends on the electricity mix. With the average European electricity mix, the usage of BEVs entails a 7-21% reduction from diesel and 26-30% reduction from petrol vehicles (Hawkins et al., 2013). When coupled with renewable energies, BEVs have an even higher potential to reduce GHG emissions. For instance, emissions of BEVs, when coupled with wind energy, could be 90% lower than emissions of a conventional vehicle (IEA, 2017b).

In fact, multiple climate change mitigation scenarios consider the transition to EVs a necessary action to reduce transport GHG emissions. For instance, the IEA's Sustainable Development Scenario, published in the World Energy Outlook 2021, estimates that 230 million electric vehicles would be on the road worldwide by 2030, representing a 12% stock share. The Sustainable Development Scenario's goal is to achieve worldwide net zero emissions by 2070 while assuring universal, reliable, sustainable, and affordable energy access. This scenario takes into account the Paris Agreement's goal of keeping global warming below 2°C. Similarly, the Net Zero Emissions by 2050 scenario, also published in the World Energy Outlook 2021, assumes that 60% of global car sales will be electric by 2030, and 50% of heavy truck sales will be electric by 2035, with no new ICE car sales. This scenario aims for net-zero CO2 emissions from energy and industrial processes by 2050 (IEA, 2021b).

The effect of EVs on air pollution depends on the vehicle's life cycle stage. During the vehicle production process, which includes the use of raw materials and production of vehicle components, pollution is greater for EVs than for ICEVs, since battery manufacturing is a coal-intensive process (Bauer, Hofer, Althaus, Del Duce, & Simons, 2015; Hawkins et al., 2013). When it comes to electricity generation for EVs, pollution is dependent on the energy mix and location. A high intake of coal in electricity generation increases EVs' PM emissions compared to ICEVs. Taking EU electricity mix as a reference, on average, EVs' PM emissions are higher than those from ICEVs. The pollution reduction potential of EVs increases as the amount of renewable energy used is higher, as shown by studies in the European case (EEA, 2016; Hacker & E.V., 2015).

At the usage stage, BEVs produce no exhaust. Therefore, primary emissions – emitted during exhaust – are reduced to zero for BEVs. Secondary particles – created in the air from pollutants emitted from the tailpipe – like PM10 and PM2.5, formed by nitrogen oxides (NOx), hydrocarbons (HC) and ammonia (NH3), are also eliminated. Thus, EVs cause less PM2.5 and PM10 than ICEVs. However, there is no consensus on the extent of the reduction: it is considered to be either slight (Timmers & Achten, 2016), or considerable (Hooftman, Oliveira, Messagie, Coosemans, & Van Mierlo, 2016). The use of BEVs also eliminates toxic tailpipe pollution from NOx (NO and NO2), HC and carbon monoxide (CO). For instance, nitrogen dioxide (NO2) is responsible for over 50,000 premature deaths per year in Europe, and causes respiratory and cardiovascular disease. Studies suggest that the savings in NOx emissions from exhaust are larger than the additional NOx emissions generated from electricity (EEA, 2016; Hacker & E.V., 2015). Other toxic, though less known, pollutants, like benzene (C6H6) and polycyclic aromatic hydrocarbons (PAH), are also reduced with BEVs. In terms of brake pollution, EVs are the better alternative. ICEVs use disc brakes to slow the vehicle down. On the contrary, EVs use regenerative braking, which minimizes brake energy usage, reducing particle pollution. On tyre pollution, results are less conclusive.

In addition, electric vehicles are more energy efficient compared to gasoline-powered vehicles (Brousseau & Saussier, 2022). Estimates suggest that EVs are two to three times more efficient than their thermal equivalent (excluding potential energy losses due to energy storage issues or the energy required for air conditioning) (U.S. Department of Energy, n.d.). An internal combustion engine generates more heat than kinetic energy. This energy is transferred from an internal combustion engine to the wheels through a mechanical process, which result in various energy losses. In contrast, the wheels of an electric car are powered directly by electric motors, resulting in an energy efficiency of roughly 90%. Electric vehicles also use regenerative braking to recapture and reuse energy that would otherwise be wasted when braking and lose no energy when stationary.

Electric vehicles are also a less noisy option compared to conventional vehicles. An ICEV produces noise coming from the power train, especially at low speeds, which impacts mostly urban areas. For an electric vehicle, the engine noise is low. EVs are almost silent when stationary. The main source of noise for an EV is the one produced at rolling. However, technological advancements have allowed to reduce noise levels coming from ICEVs. Research projects like the FOREVER project intend to compare noise emission levels coming from both EVs and ICEVs. Results suggest that for a single EV, a reduction in noise is indeed achieved, however, a real impact in noise can be obtained with a high share of EVs on roads. In a scenario where half of the urban traffic mix consists of electric vehicles with 10 dB(A) lower noise emissions and the other half consists of conventional vehicles, the overall noise reduction compared to conventional traffic will be few decibels and practically unnoticeable (Pallas et al., 2015).

Aside from reducing transport externalities, electric vehicles open opportunities for value creation and cost reduction. An example is the implementation of smart-charging and Vehicle-to-Anything (V2X). V2X describes the use of EV batteries to generate value when the car is stationed, through the provision of energy services (Thompson & Perez, 2020). Given that personal-owned vehicles are parked during most of the day, storage capabilities of the battery can generate actual value to the energy sector, while giving financial returns to owners (Kempton & Letendre, 1997). In the domain of V2X one can distinguish between Vehicle-to-Load (V2L), Vehicle-to-Home (V2H), Vehicle-to-Building (V2B), and Vehicle-to-Grid (V2G). V2L can entail an EV battery providing energy to a load, specially when it corresponds to an emergency purpose, like an energy outage or the provision of energy in rural areas with limited grid connection. V2H can entail the use of the EV battery to optimize energy consumption, or as an emergency back-up power for the home. V2B, alike V2H, optimizes energy consumption and works as an emergency back-up power at a larger scale (e.g. in commercial buildings). V2G can entail the provision of quick-response energy services (i.e. peak power, spinning reserves, and regulation) to the grid itself (Kempton & Tomić, 2005). V2X services have a high compatibility with increases of renewable energy sources, and can help with their integration. In fact, batteries can help reduce the uncertainties in the energy services provision coming from the increase in intermittency of renewable energy sources, while reducing GHG (Alirezaei, Noori, & Tatari, 2016; Lund & Kempton, 2008). A study from the International Energy Agency highlighted that the deployment of smart charging solutions for electric vehicles could increase grid flexibility while saving between $100 billion and $280 billion in avoided investment in new power infrastructure between 2016 and 2040 (depending on the quantity of EVs installed) (IEA, 2017a).

Electric vehicles also have lower operation and maintenance costs compared to ICEVs. According to a study from the U.S. Department of Energy Office of Scientific and Technical Information, the maintenance costs for a BEV are equal to 6.1 cents per mile, while for an ICEV it is 10.1 cents per mile. Regarding the total cost of ownership (TCO), which consists of all costs related to both purchasing and operating the vehicle, it depends on the annual driving distance and the vehicle class. A study developed by Wu, Inderbitzin, and Bening (2015) suggests that in some cases, specially for short distances, ICEV are expected to be the most cost-efficient technology until 2025. Otherwise, specially for long distance trips, EV can be more cost-efficient than ICEV in 2025. This is primarily due to EVs having lower operating costs per kilometre than conventional vehicles. In contrast, the capital cost of EVs remains higher than that of conventional vehicles in all circumstances.

The electric vehicle development also enables micromobility. Micromobility refers to small, lightweight vehicles (under 500 kg), driving at speeds below 25 km/h, that carry passengers for short distances. Some examples of micromobility options are e-bikes, electric scooters, shared bicycles and e-skateboards. These vehicles can be shared or personally owned and are city-centric. Micromobility intends to reduce the personal four-wheeler car use by providing an option that is cheap, sustainable, efficient and easy to use. For shared micromobility services, the integration with the public transit system gives users door-to-door options, enhancing the capabilities of the public transportation service. Companies like Uber, Lyft and Lime are proponents in the micromobility space. For instance, the American company Lime operates in many cities around the world, among which San Francisco, Paris and Rio de Janeiro. Electricity-powered micromobility options, like e-bikes and e-scooters have a battery pack and a motor to store and use the electricity, and tend to be heavier than the human-powered options. They have advantages over human-powered micromobility options since they can overcome difficult trajectories, like steep hills or long distances, with less effort and faster. The market for electric micromobility options has expanded rapidly since their emergence in 2017. According to the IAE's 2021 Gobal EV Outlook, shared e-scooters, e-bikes and electric mopeds are available in over 600 cities across more than 50 countries worldwide. China is the country with the highest stock of micromobility vehicles, accounting for 25% of the global market share (IEA, 2021a).

1.5.2 The promise of autonomous vehicles

Autonomous vehicles have the potential to revolutionize transport as we know it. First of all, owning a vehicle can become optional. AVs offer an opportunity to change consumer preferences, where people will buy a service instead of a car. Mobility as a service (MaaS) is a concept that encloses this shift from personally-owned services towards mobility provided as a service. MaaS combines public ad private transportation options into a single platform, where users can pay using one account. A significant part of MaaS is public transportation, where AVS have a great opportunity. For instance, companies like Navya and Easymile are developing autonomous shuttles to be included in public transport systems. Cities like Paris, are in tests for these shuttles. Robotaxis are also a popular application for AVs and an important enabler of MaaS. Different companies already propose the robotaxi service. For example, GM's Cruise Automation is manufacturing autonomous vehicles for the sole purpose of proposing ride-hailing services. The company launched the service in San Francisco for its employees in 2021 (Bellan, 2021). DiDi began in June 2020 the operation of its robotaxi service in Shanghai, and covers the business districts, subway stations and hotels in the downtown area (Shahan, 2020). Waymo began its robotaxi service in 2019 at its Phoenix Arizona pilot program, and launched its robotaxi service in February 2021 in a number of the San Francisco suburbs (White, 2020).

As consumers switch from ownership to service, different factors will also become more prominent in transportation. For example, the brand of the car could become less important than the quality of the service offered, which opens up possibilities to offer infotainment inside vehicles. Indeed, multiple services can be offered inside an AV. The fact that people can perform other activities instead of driving (e.g. working, sleeping, playing video games, watching movies, etc.), opens up the doorway to offer infotainment services. For example, the Cruise Origin, the autonomous car developed by GM's Cruise, proposes entertainment features, Wi-Fi connectivity and work during the travel. Netflix is already part of the offers proposed in Tesla's cars (Etherington, 2019). It is also possible to imagine that companies offer free AV rides to advertise their products or services. For example, grocery shops proposing rides to drive customers to their stores.

Autonomous vehicles are also promising in improving inefficiencies related to public transport, specially when it comes to delivering first and last mile transportation. First and last mile transportation refers to trips connecting public transport with a given destination (home, work, leisure, delivery of goods). AVs have potential in reducing these inefficiencies, specially when it comes to delivering goods door-to-door. There are examples around the world related to autonomous delivery vehicles. For example, Walmart teamed up with Cruise to begin grocery delivery in Scottsdale, Arizona in 2021. Along this partnership, Walmart has also partnered with other AV companies like Nuro, Ford and Waymo (Ward, 2020). Similarly, Amazon ordered 1,000 autonomous trucks from a startup called Plus (L. Y. Chen & Tan, 2021).

Cities also have the potential to transform with autonomous driving. As users no longer need to drive, they can do any other activity in the vehicle like sleeping or working. This can impact their living choice, since they could prefer living farther from working centers. Hence, cities can become more descentralized. In addition, land allocation can completely evolve. Surveys have found that 30% of traffic is a result of drivers looking for parking spots. AVs' promise of being shared, and more time-efficient will reduce the need for parking spaces. We can imagine future cities to have more green spaces, with bigger spaces for leisure, instead of parking spaces. Given that much of the change regarding AVs will be done thourgh the coupling with public transportation, cities, not regions or countries, can become the core of transformation.

People with disabilities can also benefit from the entrance of autonomous vehicles. The fact that they need few to no human intervention makes it easier for people with different types of disabilities to take an AV. Indeed, previous research suggest that drivers with medical conditions or disabilities could increase light-duty vehicle miles traveled by as much as 2.6% (Harper, Hendrickson, Mangones, & Samaras, 2016). Few complementary tools can also enhance the accessibility of AVs. For instance, Waymo is testing buttons with Braille to facilitate visually impaired people to use an autonomous vehicle (Bhuiyan, 2017). Besides, AVs can be designed to provide an easy way for people to board, through the scanning of the surroundings via the different sensors and cameras.

In addition, autonomous vehicles can contribute to reducing several transport externalities, such as congestion and traffic accidents. Although the pandemic decreased significantly congestion costs, due to the increase of work from home activities, lockdowns and other restrictions, congestion remains, and post-pandemics, there is no warranty that the pandemic congestion levels remain. As an illustration, drivers in Paris lost 165 hours per year in 2019 and 88 hours in 2020, making the city the sixth most congested in the world by 2020 (INRIX, 2021). Aside from the time lost, congestion also exacerbates other factors like noise pollution and fuel consumption, which provokes higher GHG emission levels and air pollution levels.

Traffic accidents correspond to another transportation externality that autonomous vehicles can alleviate. Traffic accidents are the 8th highest cause of death, all ages comprised, and the highest cause of death for people aged 5-29 years old (WHO, 2018). Traffic accidents do not only increase the death risk, but also impact inactivity, since people is less likely to take any mean of transportation when the risk of fatalities is higher. The social and economic costs associated to traffic accidents can include the cost of loss of life, medical costs, property damage, legal costs, administrative costs, pain, grief, suffering and a decrease in quality of life[8].

1.5.3 The promise of coupling of both electric and autonomous vehicle technologies

Coupling electric and autonomous mobility can increase the potential of both technologies to create value. First of all, ensuring that autonomous vehicles are more sustainable than current vehicles may be a pre-requisite. In addition, electric vehicles are a safer option for an autonomous car. Maintenance is also cheaper and easier to do in an electric car, which implies less logistics for an AV. Lastly, managing AV fleets can facilitate the provision of V2G services. Due to their complementarity, policy-makers are envisaging future mobility that is electric and automated. For instance, the Californian government states that autonomous vehicles should promote the use of zero-emission vehicles (U.S. Senate, 2021). Similarly, the European Commission in its ‘Sustainable and Smart Mobility Strategy’ proposes an action plan for future mobility that includes both electrification and automation of mobility (EC, 2020). Companies are also on-board with the natural transition to electric-autonomous mobility. GAC

[8]For the whole European Union, this cost is equivalent to €0.002 per passenger kilometers (pkm), as estimated by (Gössling et al., 2019).

Aion, the electric car spinoff of China's GAC Group teamed up in the beginning of 2021 with ride-hailing company Didi Chuxing to develop an autonomous electric car. The objective of this collaboration is to accelerate mass production through large scale commercial applications (China Daily, 2021). Tesla, since its origin, has been a proponent for fully-electric autonomous mobility. Startups like Easymile and Navya design autonomous shuttles that are electric. Other companies are opting for hybrid electric vehicles, like Ford.

However, we should note that coupling both technologies can come at a cost. Using AVs increases energy use. Some analysts suggest that these increased power needs are significant enough to drastically reduce vehicle range thus eliminating the possibility of electric autonomous vehicles. In a paper published in Nature Energy, researchers determined that electric power can supply enough energy for an autonomous vehicle without a significant decrease in range, but the effect on range is strongly influenced by sensor drag for suburban driving and computing loads for city driving (Mohan, Sripad, Vaishnav, & Viswanathan, 2020).

1.6 The challenge of scaling-up electric and autonomous mobility

1.6.1 Clash of interests between different actors

Electric and autonomous vehicles are developed by a multiplicity of actors. While many of them are incumbents in the automotive sector, others are new ventures or established companies in other sectors, like software, hardware, and energy. For example, incumbents like Renault, new ventures, Tesla, infrastructure providers, like Total, and battery providers, like Panasonic are participating in the development of electric vehicle components. Similarly, incumbents in the automotive industry (e.g., General Motors, Daimler, Toyota), new ventures (e.g., Drive.ai, Aurora), software firms (e.g., Google, Uber), and providers of hardware (e.g., Innoviz Technologies, VeloDyne, Ouster) are involved separately in the production of autonomous vehicles.

In line with the resource-based view, firms forge inter-organizational ties in order to obtain access to resources outside its boundaries to gain competitive advantage. Particularly when facing rapid-changing technologies, it is hard for firms to be able to build new competences without using external resources via inter-organizational ties (Wadhwa, Phelps, & Kotha, 2016). The most frequent type of tie consists of non-equity alliances (Rothaermel & Boeker, 2008) -

agreements between two or more parties forged to facilitate the pursuit of common strategic goal and the sharing of created value. Some other types of ties, such as equity alliances are used to create value.

To draw on their own capabilities and benefit from the capabilities of others, actors involved in the creation of both autonomous and electric vehicles are organized around innovation ecosystems. Innovation ecosystems are defined as complex networks of firms evolving from the unbundling of formerly vertically integrated industries and from the convergence of previously distinct sectors, with the objective to develop a common value proposition (Adner, 2017; Iansiti & Levien, 2004; Jacobides, 2018). Accordingly, the electric vehicle ecosystem is composed by five major components: the vehicle design and manufacture, the battery, on-board charging system, the home charging equipment and the public charging infrastructure. The autonomous vehicle ecosystem is composed by the following components:

In an innovation ecosystem, different participants draw on their capabilities to design components to the focal offer. The components have little value in isolation (Hannah & Eisenhardt, 2018), therefore each one needs to be present for a healthy ecosystem to emerge. The interdependency between participants creates new competition and cooperation dynamics in the strategic field, since they require a balance competition and cooperation to be successful. Cooperation occurs when firms jointly pursue mutual interests and common benefits. On the other hand, competition occurs when firms pursue their own interests at the expense of others (Das & Teng, 2000; Hannah & Eisenhardt, 2018). If firms cooperate extensively, they may not capture enough value to survive. If firms compete fiercely, the ecosystem may fail to form (Ozcan & Santos, 2015). Competition exists at two levels. The first type of competition is between stakeholders in the same ecosystem. Organizations compete on positions, roles, and the distribution of value between them. The second type is across ecosystems, since they compete for creating and capturing value (Adner, 2017). There is a trade-off between cooperation and competition in an ecosystem. Firms must collaborate and depend on each other to create (Ethiraj, 2007; Hannah & Eisenhardt, 2018) and impose their value proposition with respect to other ecosystems (Adner, 2006, 2017). On the other hand, firms must compete to capture value (Hannah & Eisenhardt, 2018; Jacobides, Mcduffie, & Tae, 2016).

Some examples of collaborations in the electric vehicle ecosystem are Tesla and Panasonic, where the Japanese firm provides the battery for the Tesla vehicles. Besides, GM engaged in a partnership with Uber where the automaker provides special prices to Uber drivers on the purchase of a new EV and charging accessories. autonomous vehicle ecosystem are GM and Honda, who engaged in an R&D partnership in 2018 on autonomous driving technology. Similarly, the Daimler-Renault-Nissan alliance is expanding its electric vehicle (EV) manufacturing collaboration to also explore AVs and related technologies.

Figure 1.4 shows a complete picture of the actors involved in the different features of the current mobility ecosystem.

1.6.2 High infrastructure changes

Electric vehicle technologies require high infrastructure changes to facilitate their adoption, such as the installment of chargers at homes, buildings, city streets and roads. This infrastructure is important to boost electric vehicle uptake since potential owners may be reluctant to buy an electric car if there are not sufficient stations to charge the battery –phenomenon coined in the literature as “range anxiety”. However, the installation of EV charging infrastructure is expensive, which discourages investors to provide monetary resources without counting with an established EV market. This paradox is called the “chicken and egg” dilemma –There are no charging stations if there are not enough EVs in the market, and viceversa. Indeed, studies have pointed out that investments in fast charging infrastructure often do not result in profitable financial returns (Madina, Zamora, & Zabala, 2016; McKinsey, 2018; Schroeder & Traber, 2012). The underlying reason is that with low EV adoption rates, investors cannot recover the high initial costs (Madina et al., 2016).

In Europe, a continent with strong electrification goals, we observe different dynamics of charging infrastructure deployment. When comparing the percentage of EVs with respect to the public charging infrastructure density (number of charging stations per square kilometer) for European countries with more than 0.5% EVs on the road, the panorama is diverse. France is slightly behind the European trend with around 0.06 charging points/km^2 for a 1% EV fleet size. Germany, on the other hand, is slightly ahead with with around 0.12 charging points/km^2

and 0.8% EVs on the roads. Indeed, Germany strategy consists of building public charging infrastructure, despite having a lower EV market share. Sweden has a relatively low EV per charging station ratio with 3% EV fleet size and 0.02 charging points/km^2. A similar case is observed for Denmark and Belgium. These countries' public policies have prioritized the purchase of EVs over the installation of public charging facilities (TERA, 2021).

Yet, estimates predict that the EV fleet will grow in the coming years. The deployment of charging infrastructure is thus essential to meet future demand. In the case of France, as of today, public EV charging stations account for 6% of all installed charging stations. Nonetheless, once the car fleet is converted to electric, they are estimated to account for 36% of the total number of charging stations (TERA, 2021). A report elaborated by the ICCT suggests that, in a scenario in which all new vehicle sales are electric by 2035, 7.3 million chargers, including 430 000 public chargers, will be required by 2030, which is higher than France's initial 2015 target of 7 million chargers (Bernard, Hall, & Lutsey, 2021). Particularly, denser, wealthier urban areas, such as Paris and Marseille, who are also the highest adopters of electric vehicles, have also the largest demand for public charging infrastructure expansion by 2030. This is due in part to the lower availability of home charging in these dense urban centers (Bernard et al., 2021). As a result, the implementation of public charging is a critical issue to address in order to meet the increasing demand.

The high installation costs also imply that locations should be optimized according to consumers preferences (Bitencourt et al., 2021). For example, when traveling short distances, consumers have more flexibility to adapt and charge the vehicles at home or at work. The charging stations should then be placed near city work hubs. In addition, the amount of power required to charge the vehicle may vary. Generally, users prefer a fast charging option for long-distance travels. So far, investments have been mostly placed in chargers targeted to highly frequented roads (Ji & Huang, 2018). Ensuring a well-spread network, covering less frequented areas is more challenging, and can be a barrier for the transition to electric vehicles (X. Huang & Ge, 2019).

To counterbalance the charging infrastructure demand issues, some countries, cities and regions are launching plans for electrification of roads. In France, the government dedicated

€100 million to the installment of charging infrastructure, as part of the French recovery plan, and expects to cover the French territory of fast charging at the beginning of 2023 (Ministère de l'Économie des Finances et de la Relance, 2021). Germany plans to install one million public charging stations by 2030 and has mandated that all gas stations have charging stations in their customer parking areas (Bundesregierung, 2019). In the U.S., California plans to install 250,000 public EV charging stations, out of which 10,000 provide fast charging, by 2025 (California Public Utilities Commission, 2018). The installation roadmaps are generally accompanied with tax rebates, subsidies or exemptions on electricity tax (Cansino, Sánchez-Braza, & Sanz-Díaz, 2018; Mersky, Sprei, Samaras, & Qian, 2016). Nonetheless, most of these measures are not designed to create a fast charging network that is equitably distributed in a territory (Baumgarte, Kaiser, & Keller, 2021). A challenge when deploying highly costly infrastructure is to cover the entire territory and not just high demand reasons, as it was the case of the mobile internet in Germany (Hirler, 2019), where most of the infrastructure was concentrated in urban, high demand areas, while rural areas were left behind.

On top of that, the electrification of roads will need a significant increase in electrical production. Estimates suggest that electricity demand will be at least 30% higher than current production (Brousseau & Saussier, 2022). According to the IAE Stated Policies Scenario, worldwide electricity demand from electric vehicles (including two- and three-wheelers) is of 550 TWh in 2030, nearly doubling from 2019 levels, highlighting the need to increase generation capacity (IEA, 2020). Additionally, it creates new challenges to both transmission and distribution networks. For instance, greater flexibility would be needed if EV users charge their vehicles at the same time. As of today, estimating the electricity demands is difficult, since there is a great deal of uncertainty concerning the different technologies that will be used to increase capacity and the pace of transport electrification (Brousseau & Saussier, 2022). Without proper planning, the power grid may be unable to effectively supply electric vehicles, limiting their uptake and, as a result, the achievement of decarbonization goals.

Autonomous vehicles also require big infrastructure changes. For example, roads equipped to provide real-time data on traffic and weather conditions, radio transmitters, replacing traffic lights, mobile and wireless data networks with a high capacity to handle both vehicle-to-vehicle and vehicle-to-infrastructure communication. Current roads are designed for human drivers, therefore, adapting them for AVs will require significant urban planning and investment. Even if sensor technologies are designed to understand the environment that surround the vehicle, there is still uncertainty on the necessity for dedicated roads for AVs, specially when platooning, which requires an extra effort on adapting road infrastructure. There is still uncertainty on the technology, or combinations of the technology that AVs will need to communicate with other vehicles and with infrastructure. Regardless on the technological configuration, infrastructure will play a high role in the deployment of autonomous vehicles.

1.6.3 High regulatory uncertainty

Regulations are mandatory requirements developed by policymakers that are specified by law and are enforced by the government. Standards in contrast are engineering criteria developed by the technology community that specify how a product should be designed or how it should perform. Standards have no authority, but are useful to give consistency, interoperability and safety. The need for standards and regulations has been acknowledged by different stakeholders that participate in the autonomous vehicle ecosystem. A first set of regulations and standards is needed to facilitate human-machine interaction. For example, with car's driver warning systems, there should be an understanding of how and when the technology will work, and what are the signals sent. Regulations are also useful to coordinate expectations of people that interact with an AV from the outside. For instance, it can increase pedestrians safety, by providing them with information of cars' functioning (e.g. when does the car brake). In these cases, standards must be developed to take into account diverse populations and varying expectations. Another type of regulations and standards required for AVs concern their performance. AVs, compared to conventional cars, make judgements and take decisions regarding their external environment, for which they have no control of. Then, regulations and standards help to clearly specify the environment conditions where AVs should operate and get tested (e.g. the quality of the road, lane markings and signs, the weather conditions) For instance, one possible regulation to implement that helps control the environment of AVs is the implementation of lanes strictly for AVs. Likewise, rules can limit their operation to certain areas or conditions. Finally, regulations and standards give manufacturers confidence that the technology is ready to operate, which provides them with liability protection in case there is a fault in its operation.

Currently there are few regulations in place for AVs. In Japan, the “Road Traffic Act” and “Road Transport Vehicle Act” were amended in 2019 and came into effect in 2020. These laws allowed Level 3 self driving cars on public roads, and considers the necessary features to ensure autonomous driving safety for level 3 vehicles. Both laws are being revised to include level 4 automation (Imai, 2019). In Europe, Regulation 2019/2144 specifies the safety requirements for motor vehicles and their trailers systems, components and separate technical units intended for such vehicles (European Parliament, 2019). The regulation introduces advanced safety systems for vehicles such as intelligent speed assistance, alcohol interlock installation facilitation, driver drowsiness and attention warning systems, advanced driver distraction warning systems, emergency stop signals, reversing detection systems, event data recorders, and accurate tyre pressure monitoring. The regulation comes into effect in 2022. In Germany, the Federal Act Amending the Road Traffic Act and the Compulsory Insurance Act came into effect. The act allows Level 4 vehicles in specific operating areas on public roads(Bundesministerium der Justiz, 2021)

Other countries and regions in the world have not yet implemented regulations on autonomous vehicles. In the UK, a new law proposal is being developed after receiving the results from the 2020 public consultation. The law seeks to allow self-driving automated lane keeping systems (ALKS) up to 37 mph. (Webster, 2021). In the U.S., there is no Federal regulation in place. Nevertheless, the US National Economic Council and US Department of Transportation (USDOT) released in 2016 the Federal Automated Vehicles Policy, which are standards that describe how automated vehicles should react if their technology fails, how to protect passenger privacy, and how riders should be protected in the event of an accident.

The reasons for the slow development of AV regulations are multiple. Firstly, regulatory promulgation fundamentally is an iterative and slow process, given the cycles of proposals, requests for comments, reviews and lobbying that precede rule-making. Second, the novelty, complexity and rapid evolution of AV technology create uncertainty in both rule-making effects and of the technology itself. In the context of rapid technological change, prescribing rules that will remain applicable is challenging (J. Anderson et al., 2016). Thirdly, reaching a consensus regarding the technology is difficult given the multiplicity of stakeholders and their diverging interests. Especially industry stakeholders can be resistant to regulation. They claim that technologies do not necessarily evolve in the expected direction, which can make regulations and standards obsolete, or hinder the technology's development.

Given the current state of autonomous vehicle regulation, multiple directions can be taken. First of all, governments can treat autonomous vehicles generally or specifically. A general approach of regulations implies that governments clarify the existing laws on motor vehicles to include vehicle automation. Existing agencies, who have originally regulated vehicle rules, would then be assigned to enforce the modified regulation. In addition, similar requirements will apply to automated and other vehicles. Alternatively, governments can promote a specific package of rules solely for autonomous vehicles. In this case, a more limited set of agencies would be in charge of the implementation of rules, and rules would intentionally differentiate with respect to particular rights, obligations and liabilities. Governments can also choose between being leaders in the legislative process, and go hand in hand with technological development, or to lag the policy process. Here, the trade-off is, as explained before, that leading the policy process may provide clearer rules for manufacturers, but may also become a barrier to technological progress, since technologies do not necessarily evolve in the expected direction. For example, the state of Michigan in the U.S. enacted a law that prohibits the operation of automated vehicles for any purpose other than R&D testing. In other states, with a lag in the regulatory process, it is possible to undertake other types of pilot projects (OECD, 2015). Another regulatory crossroad is the decision between uniformity or flexibility in rule design across multiple jurisdictions in a country. With a uniform design, costs and complexity of rules is reduced. However, a flexible approach might adjust more easily to regional differences. A hybrid approach can also be adopted, with uniformity for vehicle manufacturing rules but flexibility for testing.

1.7 The structure of the dissertation

The previous section emphasized three different barriers that could slow down or hinder the development of electric and autonomous mobility: the divergence of interest among stakeholders, high-cost infrastructure changes and regulatory uncertainty. Throughout this thesis work, I explore the strategies used by actors involved in the autonomous and electric vehicle ecosystem to overcome the barriers that emerge during the transition towards electric and autonomous vehicle technologies. I answer the following question: *How do actors participating in the electric and autonomous vehicle development shape their strategies to scale-up innovations in an interdependent, infrastructure-dependent, and regulatory-uncertain market?*

I explore this question by adopting three different perspectives, where each chapter concentrates on one of the aforementioned barriers for scaling-up: stakeholders' mismatch of incentives in an ecosystem, infrastructure lags and regulatory uncertainty. Figure 1.5 illustrates the structure of the dissertation. The first chapter focuses on the strategies undertaken by startups in order to overcome the bottlenecks that emerge in the autonomous vehicle ecosystem. I postulate that firms in the AV ecosystem opt for cooperating through corporate venture capital investments to resolve bottlenecks, and use formal and informal intellectual property mechanisms like patents and connections to influential third parties to avoid the risks of misappropriation of the innovation. The second chapter evaluates the strategies undertaken by firms and governments to increase electric vehicle adoption. I posit that fast charging infrastructure is fundamental to boost EV market share. The third chapter focuses on the strategies undertaken by private firms in the non-market strategies to shape regulations regarding autonomous mobility, and their alignment to market strategies. I hypothesize that firms allying in the market environment also form alliances in the non-market environment to resolve regulatory barriers. Finally, the conclusion will highlight the limitations and pinpoint further research directions.

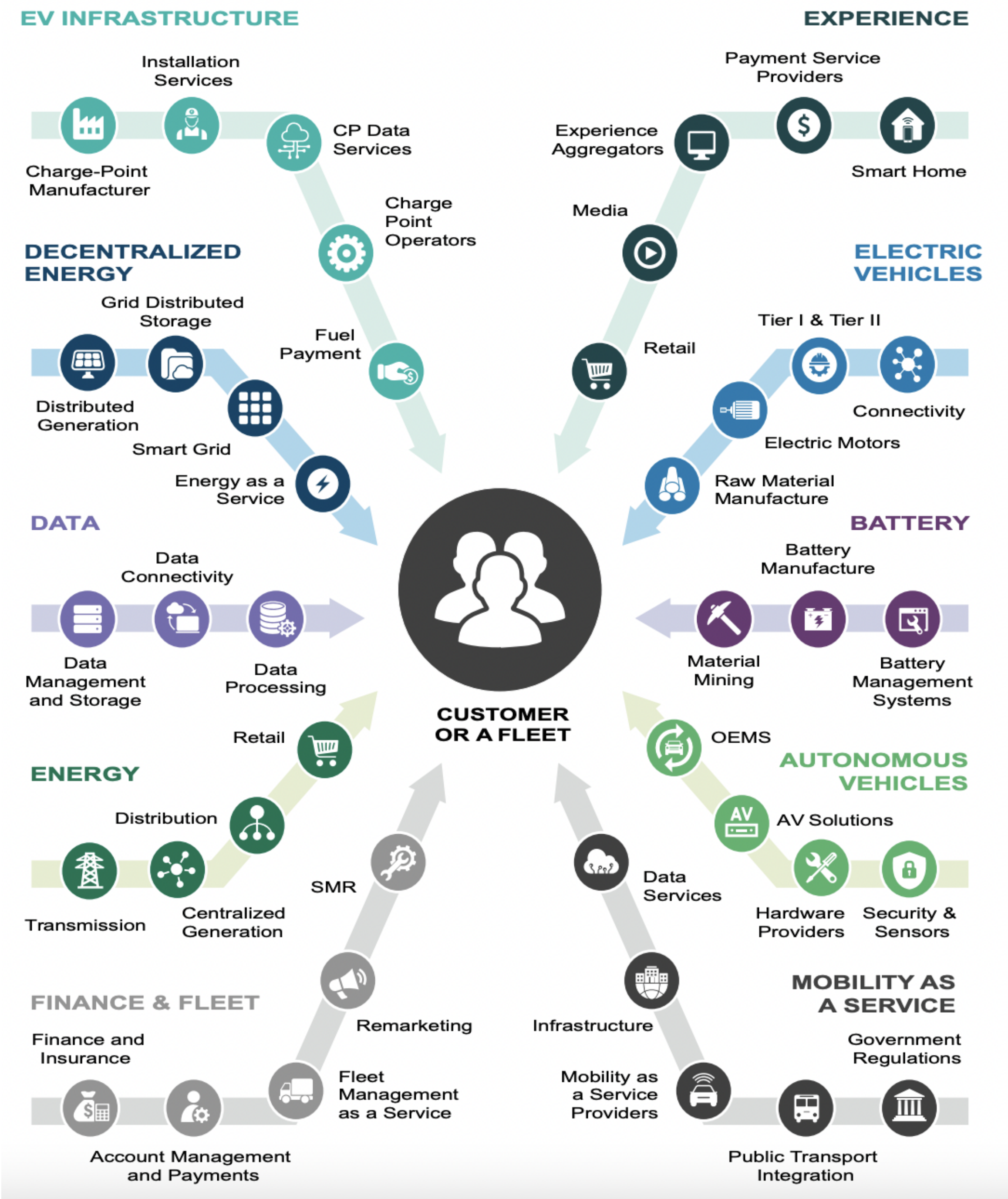

Figure 1.4: Typology of actors in the mobility ecosystem (Source: BIS Research)

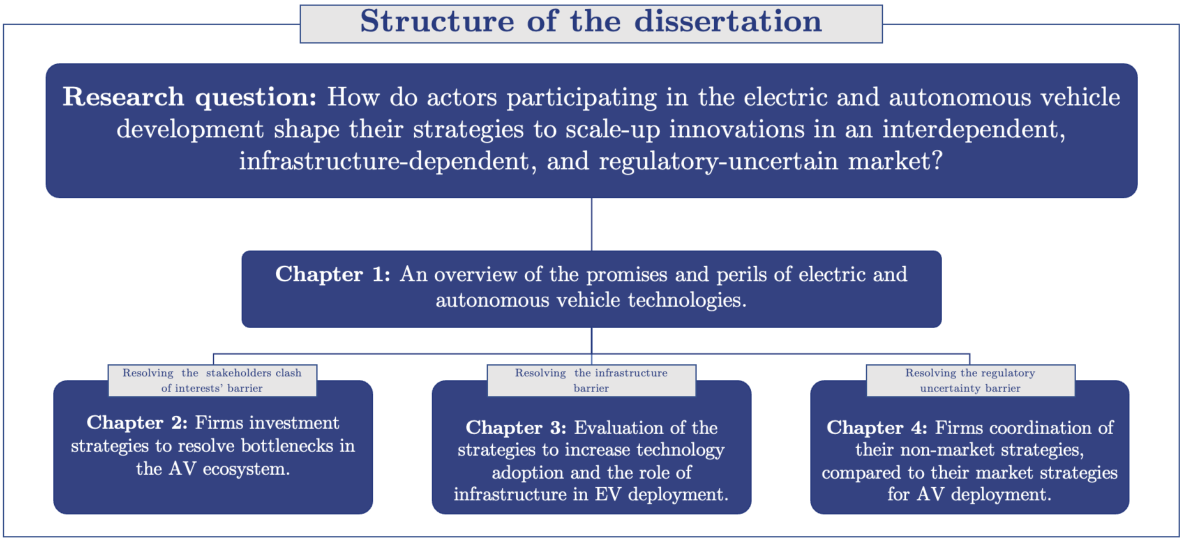

Figure 1.5: Structure of the dissertation

CHAPTER 2

NAVIGATING COOPERATION AND COMPETITION IN EMERGING ECOSYSTEMS: EVIDENCE FROM AUTONOMOUS VEHICLES START-UPS.

Maria Teresa Aguilar Rojas[1] and Jordana Viotto da Cruz[23]

Abstract

One fundamental problem of ecosystems is resolving bottlenecks - components that constrain the ecosystem growth and success due to poor performance, poor quality or shortage. Recent research shows that firms in ecosystems concentrate their investment towards bottlenecks, reallocating innovative efforts or widening capabilities. In this paper, we hypothesize and empirically show that Corporate Venture Capital programs direct their investments towards startup firms producing bottleneck components. We build and explore a novel dataset of the nascent and dynamic autonomous vehicles ecosystem. Our results suggest that equity-based ties are more likely for startups that develop bottleneck components. We contribute to the literature streams on ecosystems and entrepreneurial finance, providing evidence of how inter-firm relationships are formed in the ecosystem context.

Keywords: Ecosystems, Corporate Venture Capital, Bottleneck

[1]University Paris-Dauphine (PSL), Governance and Regulation Chair, M&O Laboratory

[2]University of Edinburgh Business School

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2.1 Introduction

In an innovation ecosystem, different participants draw on their capabilities to design components to the focal offer. The components have little value in isolation (Hannah & Eisenhardt, 2018), therefore each one needs to be present for a healthy ecosystem to emerge. However, not all components are equal. Some components constrain the growth and success of the whole ecosystem due to poor quality or shortage. The components that constrain the ecosystem at any point in time are considered the "bottlenecks". Therefore, one fundamental effort for firms operating in innovation ecosystems is lifting these bottlenecks (Basu, Wadhwa, & Kotha, 2016; Masucci, Brusoni, & Cennamo, 2020). The literature has documented some strategies firms use to resolve the bottleneck: reallocating innovative efforts in the form of patenting (Ethiraj, 2007), widening capabilities (Hannah & Eisenhardt, 2018), engaging in several forms of Corporate Venturing activities such as intrapreneurship programs (Masucci et al., 2020) and providing non-financial resources to complementors (Gawer & Henderson, 2007).

One type of Corporate Venturing activity that was not explored in the ecosystem literature is Corporate Venture Capital investments (CVC). We aim at filling this gap. In line with the aforementioned research, we posit that, in the context of ecosystems, firms with CVC programs allocate their investments in startups producing bottleneck components. This hypothesis is also consistent with the CVC literature, which demonstrates that CVC investment has strong strategic motivations. Incumbents use CVC deals to invest in startups that offer the possibility of learning about new technologies (Dushnitsky & Lenox, 2005) or that produce complementary technology whose demand will increase the incumbent's demand (Basu et al., 2016). The literature on CVC has studied investments from a cross-industry point of view (e.g., Dushnitsky & Lenox, 2005). As firms seem to be more and more involved with innovation in ecosystems (Jacobides, Cennamo, & Gawer, 2018; Kapoor, 2018), it is important to expand the knowledge about their decision in terms of their CVC investment in this new context. We therefore consider that our work also contributes to the CVC literature.

Consistent with Hannah and Eisenhardt (2018), we consider that firms in ecosystems need to balance cooperation and competition to create and capture value. In our case, the cooperation comes from the fact that incumbents provide resources that contribute to the entrant's development, which in turn benefits the ecosystem –including the incumbent's returns on investment in R&D (Ethiraj, 2007). The idea is similar to what Gawer and Henderson (2007) find in the case of Intel and to what Masucci et al. (2020) find in the case of the oil and gas firm: firms in ecosystems cooperate to improve the overall performance of the ecosystem.

We acknowledge, however, the existence of competitive forces that emerge in CVC investor-investee interactions. Such competitive forces arise due to imperfect intellectual property (IP) rights protection (Parker, 2018). Formalization and enforcement of IP protection involves high legal requirements and costs. In many industries and for many firms, the benefits of formal IP protection are not always clear as patents can be "invented around" or reverse engineered at low costs (Cohen et al., 2000; Teece, 1986). As a matter of fact, "tight" IP protection is "the exception, not the rule" (Teece, 1986). The traditional alternative to formal IP protection (patents and copyright) are trade secrets. However, they might be more effective to firms whose products relies on chemical formulas or recipes due to the fact that, in order to be protected, the firm needs to keep the underlying technology secret even after putting the product before the public (Teece, 1986).

In the absence of relevant traditional defenses (or when their efficiency is not clear), new firms may resort to alternative IP protection strategies. The relevant literature identifies the use of "timing defense", which implies forming CVC ties in later stages of the entrepreneurial venture, when technical and strategic agendas are established, and imitation becomes more difficult (Colombo & Shafi, 2016; Katila, Rosenberger, & Eisenhardt, 2008; Rothaermel & Boeker, 2008). It also reports "social defense", which consists of leaning on reputable third parties to facilitate trust in the relationship (Bae & Gargiulo, 2004; Burt, 2005; Hallen, Katila, & Rosenberger, 2014). In line with previous findings, we hypothesize that investor-investee ties will be more likely when these alternative mechanisms are available. Finally, they can rely on "downstream capabilities", particularly on marketing — related activities like brand and reputation, which are hard to imitate (P. Huang, Ceccagnoli, Forman, & Wu, 2013).

To test our hypothesis, we use data from CVC investments in the autonomous vehicles ecosystem. We identify the participants in the autonomous vehicles ecosystems as the producers components that allow the automation of the "decision-making" process regarding how the vehicle moves on streets or roads such as sensor technologies, data and simulation for autonomous vehicles, and high-definition maps (we explain all the components in Section 2.3). Data about start-ups and CVC investors come from Crunchbase. We focus on firms incorporated in the US and having at least one round of investment from Independent Venture Capital firms or CVC, which helps us to spot new ventures actively looking for outside capital. The choice also helps us to compare firms with similar ex ante quality, as external investors select firms based on observable characteristics that convey quality. We claim that VC-backing is therefore a proxy for quality, and we consider in this manner we mitigate issues concerning quality heterogeneity,—although we also include several control variables to account for this heterogeneity as detailed in Section 2.3. We identify bottlenecks as the components receiving the bulk of VC capital in a given year. The rationale is that firms resolving bottleneck components in an ecosystem tend to be those with more promising prospects in terms of financial returns Hannah and Eisenhardt (2018).

This paper is organized as follows. In Section 2.2, we outline the theoretical framework based on the relevant literature. Section 2.3 presents the context of the study, the data, and the empirical strategies. Section 2.5 shows the results, and Section 2.6 presents the conclusion and the discussion.

2.2 Theoretical Framework

Ecosystems can be described as "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialise" (Adner, 2017). The management literature identifies three types of ecosystems: business ecosystems, platform ecosystems, and innovation ecosystems (Jacobides et al., 2018).

In business ecosystems, a hub organisation coordinates a set of complementors. The French firm AirBus provides an example of a business ecosystem (Adner, 2017). The company relies on components such as engine and navigation systems which are produced by complementors. The various components need to be integrated and deliver a performance level that satisfies AirBus' strategies. The business ecosystem is envisioned as an economic community of interacting actors who all have an impact on one another through their activities, even beyond the industry boundaries.

In platform ecosystems, an intermediary connects its complementors to its users or customers. For example, app stores link mobile users and app developers, online marketplaces connect buyers and sellers. In this case, the platform's organizer, as well as all complement providers who make the platform more attractive to users, make up the ecosystem (Gawer and Cusumano, 2008). An array of peripheral enterprises are connected to the core platform via shared or open-source technologies and/or technical standards, forming a "hub and spoke" shaped ecosystem (Jacobides et al., 2018).

Innovation ecosystems consist of group of firms producing components for a focal innovation or value proposition. The personal computer can be an example of an innovation ecosystem, whereby producers of system boards, microprocessors, memory, display adapters, hard disk drives and operating systems need to coordinate to produce the focal innovation Ethiraj (2007). Similarly the production of solar panels require the coordination among suppliers of solar photovoltaic panels, racking, sales and design, installation, and finance (Hannah & Eisenhardt, 2018). In this paper, we focus on the autonomous vehicles ecosystem, which can be considered an innovation ecosystems, as different participants draw on their capabilities to design components to the focal offer.

One relevant feature of innovation ecosystems is that all components are necessary to enable the value creation process (Hannah & Eisenhardt, 2018). However, not all components play the same role: some can constraint the growth and success of the whole ecosystem if they exhibit poor quality, poor performance or shortage (Ethiraj, 2007; Hannah & Eisenhardt, 2018; Shipilov & Gawer, 2020). In the example of the personal computer, an underperforming microprocessor affects the health of the ecosystem. The components that constrain the ecosystem at any point in time are considered the bottlenecks (Hannah & Eisenhardt, 2018; Shipilov & Gawer, 2020). Ecosystems can have one or multiple bottlenecks at the same time and bottlenecks can evolve over time –components that are considered bottlenecks during a given period become the "slack" component –(the "non-bottleneck" component) after some time and other bottlenecks may emerge (Hannah & Eisenhardt, 2018; Masucci et al., 2020). Bottlenecks are not necessarily technological constraints. In the solar photovoltaic ecosystem, a non-technological related bottleneck was finance and sales (Hannah & Eisenhardt, 2018).

As bottlenecks constrain the performance of the focal value proposition, one fundamental problem for firms in ecosystems is "resolving" or "lifting" bottlenecks (Basu et al., 2016; Masucci et al., 2020). This involves directing innovative efforts towards the bottleneck component(s) to improve its performance, enhance its quality or increase its availability. For example, Ethiraj (2007) reports that in the personal computer ecosystem, the bottleneck in 1983 was the microprocessing unit. In 1984, the author categorizes the hard disk drive as a bottleneck. In 1985, the hard disk drive continued to be categorized as a bottleneck and the author identified the emergence of a new bottleneck, which was the graphics interface. Hannah and Eisenhardt (2018) identify that in the solar photovoltaic panel ecosystem, the bottleneck in 2007 was finance, as cost was high and paid by homeowners upfront. As the costs decreased and the firms started providing solutions and removing this bottleneck, sales became the new bottleneck in the ecosystem, as firms spent a significant amount of money in customer acquisition.

Past research also shows that firms may direct their investments into complementors via Corporate Venturing activities. Corporate Venturing (CV) refers to "entrepreneurial efforts in which established business organisations invest in and/or create new businesses" (Covin & Miles, 2007; Sharma & Chrisman, 1999). CV activities can be internal or external to a company, and past research shows examples of both being directed towards bottlenecks. Masucci et al. (2020) demonstrates the employment of Corporate Venturing activities to solve bottlenecks in the ecosystem of an upstream oil and gas firm. The firm uses its Corporate Venture unit to fund innovative ideas that address innovative challenges. The authors report that the firm reviews and nurtures the projects until deployment that can be in the form of internal deployment, licensing, partnering or commercializing through new ventures. Gawer and Henderson (2007) shows that Intel provides non-financial resources such as the access to intellectual property to complementors producing bottleneck components.

In the present paper, we aim at further contributing with the understanding of how the location of bottlenecks in ecosystems define the investment decisions of firms. We are particularly interested in Corporate Venturing activities, an area that is still understudied in the ecosystem literature. One of the key activities of external CV is Corporate Venture Capital (CVC) investments. CVC refers to "direct equity investments by established companies in privately held entrepreneurial ventures" (Basu, Phelps, & Kotha, 2011). While firms engaging in CVC do not necessarily invest through a dedicated channel, many create specific programs or sectors within the organisation. One of the most well-known examples of a dedicated channel for CVC is Intel Capital, the VC arm of the microprocessor producer Intel. Intel Capital invests in new ventures dedicated to activities very close to its own, such as silicon design and manufacturing, as well as in firms with operations in complementing areas such as cybersecurity, enterprise applications, cloud computing, and gaming.[4].

The objectives of CVC investments are different from those of Independent Venture Capital (IVC). While IVC firms focus on financial return, the main goal of CVC is strategic, as past research demonstrates. Dushnitsky and Lenox (2006) finds that CVC firms engage in investments with ventures developing technologies that can complement the investor's capabilities. As investors, incumbent firms perform due diligence prior to investment, scrutinizing aspects such as the management team, the business plan, target markets and products, and the technological development - with the technical assessments often performed by specialists within the investor's team (Dushnitsky & Lenox, 2006; Wadhwa et al., 2016).

Scholars also show that CVC can be used to build ecosystems (Basu et al., 2011, 2016). As previously mentioned, Intel Capital provides funding to firms that produce complementary products and services to its own offerings. The objective is to stimulate demand for PCs and, as a consequence, for Intel products (Basu et al., 2016). The literature on CVC has studied investments from a cross-industry point of view (e.g., Dushnitsky & Lenox, 2005). As firms seem to be more and more involved with innovation in ecosystems (Jacobides et al., 2018; Kapoor, 2018), it is important to expand the knowledge about their decision in terms of their CVC investment in this new context. Our work aims at filling this gap.

Considering that (i) one of the main issues firms need to solve in ecosystems is lifting bottlenecks, (ii) firms in ecosystems drive their innovative efforts towards bottlenecks, and (iii) CVC investments play a crucial role in driving incumbent firm's innovative efforts, we posit that firms

[4]Information from Intel Capital's website.

allocate CVC investment towards startups producing bottleneck components.

Hypothesis 1: Firms allocate CVC investment towards startups producing bottleneck components.

The innovative effort we focus on is cooperative in nature. Incumbents provide resources to entrants to develop and, in turn, the development of the new technology can benefit the ecosystem –including the incumbent's returns on investment in R&D (Ethiraj, 2007). The idea is similar to what Gawer and Henderson (2007) find in the case of Intel and to what Masucci et al. (2020) find in the case of the oil and gas firm: firms in ecosystems cooperate to improve the overall performance of the ecosystem.

We acknowledge, however, the existence of competitive forces that can emerge in CVC investor-investee interactions. Such competitive forces arise due to imperfect intellectual property (IP) rights protection (Parker, 2018). Formalization and enforcement of IP protection involves high legal requirements and costs. In many industries and for many firms, the benefits of formal IP protection are not always clear as patents can be "invented around" or reverse engineered at low costs (Cohen et al., 2000; Teece, 1986). As a matter of fact, "tight" IP protection is "the exception, not the rule" (Teece, 1986). The traditional alternative to formal IP protection (patents and copyright) are trade secrets. However, they might be more effective to firms whose products relies on chemical formulas or recipes due to the fact that, in order to be protected, the firm needs to keep the underlying technology secret even after putting the product before the public (Teece, 1986).

In the absence of relevant formal defenses (or when their efficiency is not clear), new firms need to learn to "swim with sharks" (Colombo & Shafi, 2016; Katila et al., 2008), resorting to alternative manners to protect their IP. Katila et al. (2008), Rothaermel and Boeker (2008) and Colombo and Shafi (2016) investigate the use of the "timing defense", which implies forming CVC ties in later stages of the entrepreneurial venture, when technical and strategic agendas are established, and imitation becomes more difficult. In line with these findings, we posit that in an ecosystem, startups may adopt a similar attitude. Therefore a CVC investor - investee tie will be more likely for more established startups.

Hypothesis 2: In an ecosystem, a CVC investor-investee tie is more likely when startups are more established.

The CVC literature points out that startups may also use "social defense", which consists of leaning on reputable third parties to facilitate trust in the relationship (Bae & Gargiulo, 2004), Burt (2005), and Hallen et al. (2014). The channel of the "social defense" studied in the literature is Independent Venture Capitalists (IVCs): by syndicating with other firms in several investment deals, IVCs occupy a given position in the VC firms network. Consistent with the network theory (Easley & Kleinberg, 2010; Jackson, 2008), actors placed in more central positions in this network can better align and discipline potential CVC deals. More central parties tend to be equipped with more and better information enabling them to identify incumbents that would be less likely to behave opportunistically (Hallen et al., 2014). Additionally, more central parties can threat to discipline potential misbehaving partners once they can terminate current ties, avoid future ties, or broadcast information about opportunistic behaviour that could damage the offending party's reputation (Hallen et al., 2014).[5] We therefore write our third hypothesis as:

Hypothesis 3: In an ecosystem, a CVC investor-investee tie is more likely when startups are linked with more central IVCs.

Another alternative for startups is to resort to their "downstream capabilities" which refer to manufacturing, marketing, or other assets required to commercialize innovation. When the downstream capabilities are strong, the innovation is hard to imitate. One straightforward example that resonates with our empirical context is marketing: firms invest in marketing to spread awareness about the product among potential consumers, to convey quality through the

[5]The fact that IVCs can serve as a social safeguard for entrepreneurs does not mean that IVCs do not display opportunistic behaviour. (Broughman, 2010) discusses issues related to opportunistic behaviour between entrepreneurs and IVCs, however we abstain from deeper discussions on the topic in the present paper to focus on the issues concerning potential IP misappropriation.

construction of a brand, and to build reputation. These two last properties are hard to imitate and appropriate by third-parties (P. Huang et al., 2013). Therefore, we hypothesize that:

Hypothesis 4: In an ecosystem, a CVC investor-investee tie is more likely when startups possess strong downstream capabilities.

While the timing defenses, social defenses and downstream capabilities were explored in the CVC literature, past research focuses on cross-industry relationships. In our case, we are interested in investigating whereas the alternative mechanisms to protect IP are equally relevant in an ecosystem context.

2.3 Empirical Context

2.3.1 The Autonomous Vehicles Ecosystem

Ecosystems can be analyzed in different manners, depending on the focus of the study. Jacobides et al. (2018) identify three research streams dedicated to ecosystems, each one featuring one distinct view. The "business ecosystem" research stream views the organisation of participants around a "hub firm" which coordinates a set of complementors. The French firms Thales Alenia Space (Azzam, Ayerbe, & Dang, 2017) and AirBus (Adner, 2017) consist of two examples of business ecosystems cited in the literature. The "platform ecosystems" stream study issues regarding firms that connect to a central platform via a shared technology or technical standard, eventually gaining access to the platform's customers. Examples include the software providers to the SAP system and video game developers (Jacobides et al., 2018). The "innovation ecosystems" consist of groups of firms producing a focal innovation or value proposition. For example, Ethiraj (2007) explores the personal computer ecosystem and Hannah and Eisenhardt (2018) study the solar photovoltaic panels ecosystem. We consider an autonomous vehicle (AV) as an "innovation ecosystem". The AV ecosystem can be considered an innovation ecosystem, as it consists of a group of firms producing components such as radars, cameras, GPS and maps for a focal innovation or value proposition (Adner, 2017; Jacobides et al., 2018).

Defining the boundaries of an ecosystem is perhaps one of the most challenging steps in this study due to potential overlapping with other ecosystems. For example, an autonomous vehicle requires parts to run using electricity, and these parts belong to the electric vehicle ecosystem (Y. Chen, 2018; Weiller, Shang, Neely, & Shi, 2015). While such overlapping is likely to exist in this and many other contexts, treating overlapping ecosystems would require a more complex treatment of our data. We therefore focus on the necessary components for an autonomous vehicle to move from point A to point B with some level of automation in the "decision-making" process.

To determine the necessary components for an autonomous vehicle to function, we first explore its definition and taxonomy. The Society of Automotive Engineers (SAE) defines 6 levels of automation for on-road vehicles to help clarify the boudaries between fully human-driven vehicles and AVs. Figure 2.1 illustrates the taxonomy[6][7]. Autonomous vehicles can provide several types of services. For example, Amazon has autonomous vehicles in test for the delivery of goods sold on its platform. TuSimple produces components for autonomous trucks. Navia delivers autonomous vehicles that operate in some airports as shuffle buses transporting passengers from one terminal to another. Uber and Lyft are in the test phase of vehicles to complement (or eventually substitute) the services provided by current complementors (drivers). For all these different types of applications, we define the key elements, or components that allow the automation of the "decision-making" process regarding how the vehicle moves on streets or roads. Table 2.1 provides with a list of the components interacting in the AV ecosystem.

Firms in the AV ecosystem choose to specialize in one component or diversify their operations, entering into several components, adopting what Hannah and Eisenhardt (2018) calls a "system strategy". AVs are more modular than traditional vehicles. This means that they are not manufactured as a complete product, but constituted of different components that, due to its digital characteristics, are never finished. In addition, they do not need to be redesigned or reproduced to be improved, but they improved constantly. This also implies that some actors

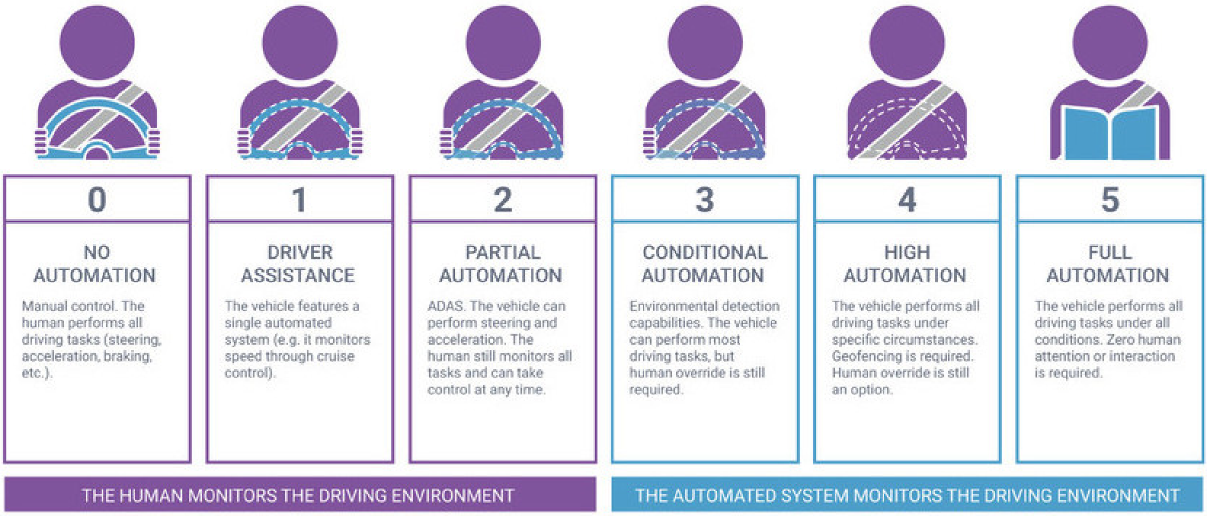
[6] Insofar, Level 2 and 3 vehicles are undergoing mass-production. Levels 4 are allowed to operate in certain locations around the world, while level 5 vehicles are in the test phase.

[7] This taxonomy has been adopted by the U.S. Department of Transport (National Highway Traffic Safety Administration - NHTSA).

Table 2.1: List of Components in the AV Ecosystem

Component	Description
LiDAR	Detects incoming objects by capturing a 3D rendering of the vehicle's surroundings, using a 360° field of vision. Infrared sensors send out pulses of laser light in multiple directions at a fast rate and measure the time it takes for the beam to bounce back. *Companies:* Luminar and Aeva.
Radar	Detects incoming objects through radio waves. The radio waves reflect on the object and return to the emitter, giving information on the speed and location of objects. *Companies:* Metawave and Echodyne.
Camera	They can identify the colors and fonts of objects, which is important for detecting information such as traffic lights, road signs, and lanes, but they are not as effective at assessing distance and speed. *Companies:* Waylens Inc. and DreamVu.
Computer vision	Set of techniques used to interpret image-based data by computers. Deep neural networks are, so far, the dominant approach to interpreting video and images. Other approaches focus more on extracting features, such as color spaces or gradients and edges, from the image. *Companies:* Deep Scale and Deep Vision.
Data & Simulation	Data obtained during test rounds trains the algorithms of the system and validate their safety. Simulation technologies consist on AI that generate or augment data sets to generate driving data that is difficult or time-lengthy to collect. *Companies:* Mighty AI and Parallel Domain.
High-definition maps	HD maps contain information on roads, road signs, crosswalks, lane sizes, among others. They are also completed and updated by data collected by other sensors. HD maps assist the car in determining what the world around them look like. *Companies:* Carmera and DeepMap.
Localization technology	combination of GPS, inertial measurement sensors, and/or GNSS, responsible for determining the exact location of the vehicle. and helps the sensor fusion component with the "map matching" task, which consist on referencing physical locations of detected objects. *Companies:* Automile and Optimus Ride.
HMI	or *Human Machine Interface*. Permits interaction between users and the machine. There are multiple types of HMI, such as interfaces to change the route or driving alerts. *Companies:* Apollo Voice and Zendrive.
V2X	or *Vehicle-to-everything*. It corresponds to the vehicular communication system that allows the vehicle to communicate and exchange information with infrastructure (e.g. traffic lights), pedestrians (e.g. alerts), or other vehicles (e.g. localization, speed, etc). *Companies:* Savari and Kymeta.
Software & OS	Allows AVs to develop and implement a variety of AV applications, including perception, mapping, localization, path planning, control and natural language processing. *Companies:* Drive.ai and PlusAI.
Cloud	Utilizes worldwide networks to link hardware to software environments offer on-demand data storage and processing power to share information and scale the vehicle's computing needs. *Companies:* Veniam and Renovo Auto.
Teleoperation	Monitor an AV from a single controller, especially in cases where algorithms fall short on providing a solution to new and complex situations. *Companies:* Scotty labs and Phantom Auto.
Cybersecurity	Due to the large volumes of data shared in real time, AVs require protection from cybercriminal activity. A cybersecurity software and platform detects and protects against cyberattacks. *Companies:* Trillium Secure and Karamba Security.

Figure 2.1: Levels of driving automation (SAE, 2021; Synopsys, n.d.)



could bundle all components into one focal offer —the autonomous vehicle, playing the role of system integrators (e.g. OEMs).

Firms producing components for the autonomous vehicle ecosystem have been attracting the attention of CVC investors. For example, May Mobility, a startup developing autonomous cars, managed to raise 11.5 million dollars in its seed round from Toyota AI Ventures and BMW i Ventures (the venture spin-offs of Toyota Motor Company and BMW Group, respectively), alongside other VCs. Likewise, DeepMap, a startup specialized in high-definition mapping solutions for AVs, raised 60 million dollars for its Series B round from Nvidia GPU Ventures and Robert Bosch Venture Capital, among others.

2.4 Data and Empirical Strategy

2.4.1 Sample

We identify startups in the autonomous vehicles ecosystem in two ways. First, we used the Crunchbase categorization ("automotive", "autonomous vehicles", and with a desk research on startups participating in similar efforts (e.g., firms having signed contracts with local governments to test autonomous vehicles). We focus on the firms incorporated in the United States. Only firms having received at least one round of investment from IVCs or CVCs are included in the sample[8]. Our objective is twofold. First, it allows us to identify firms that were actively looking for outside capital. Second, when receiving investment from external sources, entrepreneurs show the viability of their technology (Davila, Foster, & Gupta, 2003; Hellmann & Puri, 2000; Katila et al., 2008). In a similar vein, this choice enables us to compare firms with similar *ex ante* quality, as external investors select firms based on observable characteristics that convey quality. Blevins and Ragozzino (2018) show that VC-backed firms are more likely to have a successful exit via an IPO or an acquisition in comparison to their counterparts non backed by VCs. We claim that VC-backing is therefore a proxy for quality, and we consider in this manner we mitigate issues concerning quality heterogeneity, —although we also include several control variables to account for this heterogeneity as detailed below.

The main source of information for our dataset is Crunchbase, a crowdsourced database with information on innovative companies and investors in several countries. Crunchbase relies on information coming from venture capitalists, angel investors, and other types of investment firms that feed the website monthly with updates on their portfolio. Entrepreneurial firms that aim at external investors can also include their information on the website. It has been growing as a reliable source of information for investors and researchers (Tarasconi & Menon, 2017), as it can be compared with other databases such as the OECD Entrepreneurship Financing Database, VentureXpert, and PwC (Dalle, den Besten, & Menon, 2017). From Crunchbase, we collect information on the new ventures' activities and characteristics: founded date, headquarters' location, and the experience of the founding team (number of founders and if at least one member of the founding team has experience in entrepreneurship).[9] We also retrieve the number of funding rounds with the respective type of each round (e.g., Seed, Series A), and the date of announcement of each round. In order to deal with eventual missing data on Crunchbase, we consult the firms' websites and social media as well as press articles. Information from the CVC firms include their location, their activities as investors (since when they invests), the total portfolio firms, the ratio of portfolio firms to exits weighted by the experience in investing (as

[8]We drop firms that have received funding only from angel investors because CVCs would not participate in these rounds, and therefore they would not have been able to receive CVC.

[9]Alternatively, we also use a dummy indicating if at least one founder has experience with a successful exit via acquisition or IPO.

measured by the first CVC investment), its successful exits to date. We also identify the IVCs participating on each round. We collect information on the Venture Capital (VC) firms investing in each round with the objective of calculating the network position of each VC.

We enrich the main dataset with information from other sources. We categorize firms into sectors and industries using the Global Industry Categorization Standard (GICS), a classification system developed by MSCI and Standard & Poor's Dow Jones[10] Our choice to use the GICS instead of the North American Industry Classification System (NAICS) —the official classification system —is that private firms are not constrained to register, and many firms in our sample do not have a number. We also include information on patents from Patentscope, using the name of the firms as assignees of the respective registration.

We obtain information on firms' components by collecting information on the product developed by each startup from Crunchbase and the companies' websites. To group products into components, we create a categorization based on press and industry articles. Following P. Huang et al. (2013), we consider the downstream capabilities of the firm as proxied by the existence and number of trademarks associated with the firm. Trademarks have the property to protect firm's intangible assets such as brand and reputation (Fosfuri, Giarratana, & Luzzi, 2008; P. Huang et al., 2013). Information on trademarks comes from the Trademark Electronic Search System. Similarly to the case for patents, we searched for trademarks that were assigned to the firms in the database. In all the cases, patents and trademarks were hand-checked for ambiguity. We use only software trademarks that are currently "live" as of the date of observation.

We identify 86 startups in the ecosystem. Some examples of firms in our dataset comprise recently incorporated ventures such as Carmera (HD maps producer, founded in 2015), Luminar (LiDAR producer, founded in 2012) and Lunewave (radar producer, founded in 2017). Table 2.2 displays information about some of the firms in our sample.

On the incumbent side, we first identify all the investors on each round of all the ventures, and then categorize them as Corporate Venture Capital investors if (1) they are categorized as such on Crunchbase (our main source of data, as detailed below), or (2) the organisation's main

[10]The methodology was developed in 1999, and is updated periodically to reflect transformations in the economy. For example, in 2018, the GICS included the Communication Services sector to capture the evolution of the Internet–based activities that resulted in the integration between telecommunications, media, and internet companies).

Table 2.2: Examples of startups in our sample

New Firm	Location	Year Founded	Component
Lunewave	Tucson (AZ)	2017	Sensors
Carmera	Brooklyn (NY)	2015	Maps
May Mobility	Ann Arbor (MI)	2017	LiDAR, radar, camera, data, simulation, software & OS
TuSimple	San Diego (CA)	2015	LiDAR, radar, camera, data, simulation, software & OS
AEye	Pleasanton (CA)	2013	Camera

activity (or its parent's organisation main activity) is not in finance. Following Dushnitsky and Shaver (2009), we do not consider CVCs from financial corporations, as they are more likely to pursue investments to diversify their portfolio rather than to gain a window over new technologies. We consider investors located in any country.

We identify 69 incumbents. Table 2.3 displays other examples of incumbents that invest via CVCs in our sample.

Table 2.3: Examples of CVC investors in our sample

CVC	Parent	Year created	Investments	Exits
Intel Capital	Intel	1991	1,309	364
GV	Google	2008	650	124
Qualcomm Ventures	Qualcomm	2000	334	70
General Motors Ventures	General Motors	2010	20	3

2.4.2 Bottleneck Identification

The literature in ecosystems employ several strategies to identify bottlenecks. Ethiraj (2007) and Adner and Kapoor (2010) use news articles and product reviews in specialized publications to identify bottlenecks. Hannah and Eisenhardt (2018) identify bottlenecks from their interviews and from archival data.

In the present paper, we use the existing literature to inform the decision of the bottleneck identification. Ethiraj (2007) and Hannah and Eisenhardt (2018) demonstrate that firms who are able to identify the bottleneck and enter or innovate in the corresponding component are those with more prospects of performance. As the startups in the bottleneck component are the most promising in terms of financial returns to investments, they are more likely to attract investments from venture capitalists (IVC). We then take each startup in our sample and list all the components it develops. For each round of investment a given startup receives, we consider an investment in all its components. We then sum the investments each component received in any given year. With this data, we develop a measure that indicates the bottleneck component per year, which consist in obtaining the intensity of the component (i.e. the number of investments in the component) in a year. The component with the highest intensity in a year is assigned as the bottleneck.

We are aware of the potential endogeneity issues arising from this specification of the bottleneck. Indeed, since our bottleneck measure is constructed from the IVC investments, there might be a relationship between the willingness to invest of CVCs and IVCs in a startup, which could lead us to bias estimators. Nevertheless, other potential bottleneck measures have their own shortcomings. For example, identifying bottlenecks from peer-reviewed publications may not reveal in real time the bottleneck component, since the peer-review process can last several months. The lag in the publication process can be of around 9 months for engineering papers and around 18 months for business and economics papers to be published, since the submission to a journal (Björk & Solomon, 2013). Measuring the bottleneck through patents has similar shortcomings. In the U.S., it takes about 22 months to get a patent approval after passing through all the steps for filing it (Upcounsel, n.d.). Besides, as observed before, in industries with "weak" appropriability regime, patenting is the exception and not the rule. The identification of bottlenecks through interviews can also entail different biases coming from the misreporting our miss-interpretation of the interviewees answers.

Table 2.4 shows the bottleneck components for each year of the sample, according to the bottleneck intensity measure.

Table 2.4: Bottleneck components per year in our sample

Year	Component
2009	HD maps
2010	computer vision
2011	computer vision
2012	computer vision
2013	HMI
2014	LiDar, radar, camera, computer vision, data & simulation, localization, HMI
2015	LiDar, radar, camera, computer vision, data & simulation, localization, HMI
2016	LiDar, radar, camera, computer vision, data & simulation, localization, HMI
2017	LiDar, radar, camera, computer vision, data & simulation, localization, HMI
2018	LiDar, radar, camera, computer vision, data & simulation, localization, HMI

We consider other approaches for determining the bottleneck (see section 2.5.1), such as obtaining the component with the highest centrality in a network per year. This methodology consists on drawing a network of nodes that are connected among each other through an specific link. In this case, a component is linked to another if an IVC invested in both components in the same year. Then, the nodes correspond to the components, and the links correspond to an IVC common investment in components. According to the position in the network, we can rank components centrality. However, we do not adopt it as our main approach due to lack of links in the initial years of our sample, since IVCs did not realize investments in multiple components in a year than until 2014.

2.4.3 Empirical Strategy

Our unit of analysis is a startup-incumbent dyad during a startups' funding round *t*. We consider that each funding round captures the stage of development of a startup, and therefore funding rounds are reported in an ordinal fashion. (The first VC-backed funding round will be the round number 1, for example.) We analyze the probability of a tie to form between the startup and the incumbent in the dyad during the focal funding round. The number of observations is the number of dyads in the sample (13,869)[11].

Our estimation is expressed with the following equation:

$$Invest_{ijt} = \alpha + \beta_1 Bneck_{it} + \beta_2 Age_{it} + \beta_3 VCentral_{it} + \beta_4 DR_{it} + \alpha W_{ijt} + X_{it} + \gamma Z_j + \epsilon_{ijt} \tag{2.1}$$

where $Invest_{ijt}$ represents the dummy variable taking the value 1 if an investment between the firm *i* and CVC firm *j* is realized, and zero otherwise, $Bneck_{it}$ represents a dummy variable taking the value 1 if the firm *i* produces the bottleneck by the time of funding round *t*, and zero otherwise, Age_{it} represents the age of firm *i* during the funding round *t*, $VCentral_{it}$ represents the eigenvector centrality of the most central VC investing in firm *i* during funding round *t*, DR_{it} represents the downstream resources of firm *i* during the funding round *t*. W represent control variables for dyad *ij* at the time of funding round *t* (for example, the number of patents at the time of funding round *t*), X represent control variables for firm *i* at the time of funding

[11] To deal with missing data for one company in our sample (*Ushr*) in the variable *Startup experience* , we replaced the missing values by -0,1. The rest of the variables had complete data and no further manipulation was employed

round t (for example, the number of patents at the time of funding round t), Z is the vector of control variables for CVC j (for example, if the investment unit is a separate arm from the organisation or if the operations and investment happen under the same organisation), and ϵ_{ijt} is the error term.

Dependent Variable

The dependent variable is a dummy equal to 1 if an investment between the CVC-startup pair is realized, and zero otherwise. There are 163 dyads having formed ties and 13,869 dyads not having formed ties. It is important to take into account that this approach considers all the potential investments and the realized investments, which are, by nature, small in proportion (Dushnitsky & Shaver, 2009). As a matter of fact, the proportion in our paper is higher than extant literature, given that we are focused on a single ecosystem, contrary to prior studies. For comparison, Dushnitsky and Shaver (2009) report 167 realized investments for all the 143,202 potential investments, and Colombo and Shafi (2016) report 56 formed ties and 47,652 unformed ties.

Independent Variables

Our main independent variable, $Bneck_{it}$, is defined as a binary variable taking the value 1 if the startup in a given dyad produces a component that is considered a bottleneck in the focal year and zero otherwise. We identify 11 components: LiDar, radar, camera, computer vision, data & simulation, HD maps, localization technology, HMI, V2X, software & OS, cloud, teleoperation and cybersecurity. The component (or set of components) that constitutes the bottleneck is the one that has the higher number of investments by IVCs per year.

To capture the competitive dynamics that emerge in CVC investor-investee relationships, we include a set of independent variables that represent the different informal mechanisms adopted by firms to protect their intellectual property. Firstly, we consider that when firms are more mature, technical and marketing agendas for their innovation are better established, increasing the barriers to misappropriation. Age_{it} refers to the stage of development of an innovation. It is defined as the age of the firm at the time of the focal round.

Second, we consider whether startups are backed by well-connected VCs. To construct the $VCentral_{it}$ variable, we collect information on all the investments made by VCs in the U.S., and create dyads for each co-investment between any pair of IVCs. Next, we obtain the eigenvector centrality for each VC per year (i.e. a measure indicating the influence of IVCs). We then attribute the highest eigenvector centrality score to each startup. Startups being financed by VCs with the highest centralities are those with higher social defense mechanisms.

Thirdly, we account for downstream capabilities, which refer to manufacturing, marketing, or other capabilities required to commercialize innovation. We define the DR_{it} variable as the cumulative number of trademark registries a firm possesses by the time of the focal round. Alternatively, we consider a variable counting the number of "live" trademark registries.

Controls

We include a set of control variables in our estimation. We firstly include formal IP protection. Despite the imperfect IP right protection (due to high costs and requirements), legal IP defense mechanisms, like patents or copyright, are still used by startups to protect their intellectual property, and are important to take into account in our estimation. Hence, we measure the patent stock of an entrepreneurial firm as the number of cumulative patents obtained by the firm including the focal year (Hallen et al., 2014).

Opportunistic behaviour might be more likely when both, the CVC (or its parent firm) and the entrepreneur are in the same industry, as the CVC possesses greater ability and inclination to imitate (Dushnitsky & Shaver, 2009). Indeed, prior literature show that CVC-startup ties are more likely to be formed when both firms are located in the same industry (Dushnitsky & Lenox, 2005). To control for this factor, we construct the variable *industry overlap*. We use the 4-digit level of the GICS code (Industry Group) to attribute one industry to each firm in the sample. Then, the variable *industry overlap* is a dummy variable taking the value 1 when both firms in the dyad share the same industry, and zero otherwise.

The likelihood of a tie formation between a CVC investor and a startup depends the awareness of one part about the other (Dushnitsky & Shaver, 2009). Assuming that a closer geographical location among firms increases the likelihood of tie formation, we calculate the euclidean distance among the startup and the CVC. In addition, we include controls for regions with sophisticated entrepreneurial development, namely dummies for the Silicon Valley[12].

The quality of the firm is an important measure to control for, as it might influence the likelihood of an investment of a CVC into a firm. First, entrepreneurial teams with greater quality will present greater ability in choosing investors. Second, the quality of entrepreneurial teams and of firm consists of positive signals for investors —including CVC. Past research has considered the success of a startup in the form of an IPO or an acquisition as a measure of quality. As many of the firms in our sample are still young, we are unable to employ this strategy. However, some of the variables we use can capture, at least partially, the underlying quality of the firm as reported in the literature on new ventures. For example, past experience with successful entrepreneurial ventures is associated with greater success of the new venture, and therefore greater quality as measured by the IPO. In this case, our variable on the entrepreneurial team's experience with exits captures partially quality. Other quality signals for entrepreneurial ventures are the existence of patents and strategic alliances (see, for example, (P. Huang et al., 2013) and (Baum & Silverman, 2004)).

Concerns about imitation might be higher when the CVC's investment program holds tight relationship with the parent firm, as the operational team might be more involved with the investment activities (Dushnitsky & Shaver, 2009). We include the dummy "VC arm" that takes the value 1 if the investor is a separate organisation from the parent firm (e.g., Intel Capital) and zero if the investment comes from the parent firm itself (e.g., BestBuy).

Finally, we control for the ratio of CVC/IVC inflow in the focal year. This data comes from CB Insights, a branch of Crunchbase dedicated to produce aggregate information on venture investments.

Tables 2.5, and A.1 contain the summary statistics and the correlation values, respectively, for the variables included in the estimation. The ratio of realized to unrealized CVC investments in the sample is 0.01, with 163 realized CVC investments for 13,869 possible ties, which, as explained before, is expected given the nature of the comparison. Dyads concerning bottleneck

[12]Following prior work (Guzman & Stern, 2015), we define the Silicon Valley area as the cities located in Santa Clara and San Mateo counties: Campbell, Cupertino, Gilroy, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Morgan Hill, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo and South San Francisco.

components account for 26% of the sample.

Table 2.5: Summary Statistics

	Mean	S.D	Min	Max
1. DepVar	0.01	0.11	0	1
2. Bottleneck component	0.26	0.44	0	1
3. Firm age	2.14	2.00	0	15
4. Connectedness	0.05	0.10	0	0.69
5. Trademarks	2.54	5.57	0	60
6. Patents	7.52	14.70	0	101
7. Industry overlap	0.16	0.36	0	1
8. Geographical distance	95.60	93.40	0	309
9. Silicon Valley	0.33	0.47	0	1
10. Startup experience	0.77	1.17	0	4
11. VC arm	0.45	0.50	0	1
12. CVC/IVC ratio	0.27	0.04	0.17	0.32

2.5 Results

Table 2.6 present the full models, predicting the likelihood of an entrepreneurial firm and a CVC to form a relationship. Model 1 to 4 measure the bottleneck as the intensity of the component in a year. We include the network measure of bottlenecks as a robustness check in section A.2. In the Appendix, we present other specifications, excluding some variables at each time, for comparison with the main results.

One concern given the nature of our data is the rarity of the events in the sample — the binary dependent variable is constituted by significantly fewer ones than zeros. In this case, a logistic estimation can sharply underestimate the probability of rare events. We account for this concern and perform an alternative method developed by King et al. (2001). The rare-events logistic method is used in order to avoid the potential bias that may arise for data in which events are rare. Model 1 shows the rare events logistic regression results.

Since each investor and startup entered the sample multiple times, we report clustered standard errors by investor and by startup, separately (Hallen, 2019). Model 2 presents the results for a simple logit model corrected for heteroscedasticity and clustered by investor. Likewise, model 3 corresponds to a logit model corrected for heteroscedasticity and clustered by startup. As an alternative, we control for venture heterogeneity by using the generalized estimating equations (GEE) regression method (Hallen et al., 2014; Katila et al., 2008). The GEE method accounts for auto-correlation that arises since each venture is included repeatedly across multiple rounds in our sample. Results from the GEE method are shown in Model 4.

Consistent in all models, we find that incumbents are more likely to form equity-based ties with startups that specialize in the bottleneck component, confirming *hypothesis 1*. This suggests that incumbents couple their corporate strategy to their ecosystem strategy by investing in the component(s) that could hinder the development of the ecosystem. Focusing on the bottleneck components allows established firms to resolve them, create and capture value within the ecosystem and gain strategic advantage. This results highlights the cooperative dynamics of ecosystem: For a value proposition to materialize, companies cannot innovate alone and resort to cooperation to improve the overall performance of the ecosystem.

We also confirm the presence of competitive dynamics in our results. Under the potential misappropriation of the innovation, due to imperfect IP protection rights, the presence of alternative or "informal" defense mechanisms influences the likelihood of firms to form an investment partnership. Results suggest that the more the age of the startup at the focal round, the higher the likelihood of tie formation with a CVC, confirming *hypothesis 2*. *Timing defense* mechanisms (i.e. having a more mature innovation at the time of the round), make it more difficult for CVCs to imitate the startup's innovation and act as a security mechanism in equity-based alliances. In addition, we find that startups are more likely to tie with a CVC when they are backed by well-connected third parties, confirming *hypothesis 3*. The underlying mechanism is that influential third parties possess valuable information on the reputation of CVCs, preventing entrepreneurial firms to tie with CVCs that misbehave. This result indicates that firms in this ecosystem recur to *social defense* mechanisms to protect their intellectual property, reducing the uncertainty to form an investment tie. On the contrary, we could not confirm *hypothesis 4*. We suspected that firms downstream capabilities (such as registered trademarks) would act as a defense mechanism in a CVC relationship, since they provide firms with marketing resources that might protect their IP. However, we did not find evidence that firms' trademarks influence the likelihood of tie formation between a CVC and a startup.

We also observe that the likelihood of tie formation is higher when startups have a higher patenting activity. We can deduce that, in spite of the high legal requirements and costs related to their formalization and enforcement, formal mechanisms are used to protect IP.

Contrary to prior literature, we do not find evidence that a CVC-startup tie is more likely to be formed if both firms belong to the same industry. Literature suggests that corporate Venture Capitalists are interested in backing entrepreneurial firms in their industry, since they gain window to new technologies in their industry. At the same time, startups are interested not only in the access to capital, but also in the non-monetary resources that CVCs could offer them, such as access to infrastructure, or the *savoir-faire* of a CVC in the industry. However, we believe that, in innovation ecosystem, the interest is the focal product and not the specific technologies in the industry.

As for the geographical controls, we observe that the closeness between the two organisations increases the likelihood of a CVC-startup investment tie. As Corporate Venture Capitalists do not have complete information on all the innovative firms in the industry, this result is expected, since both firms are more likely to be aware of the other (Dushnitsky & Shaver, 2009). We also find that startups established in the Silicon Valley are more likely to enter in a CVC relationship.

Investments among a CVC and a startup are more likely to realize when the investor is a separate organisation from the parent firm. This result indicates that concerns about imitation are higher when the CVC's investment program holds tight relationship with the parent firm, as the operational team is more involved with the investment activities.

To control for startup quality of the firm, we use the experience of the founding team on venture creation. We expected that firms for which a member of the founding team had a past experience with ventures will influence the likelihood of tie formation with a CVC. However, we cannot conclude that startup experience influences the likelihood to form an equity-base partnership. To further analyze this variable, it would be interesting to explore other measures of startup experience.

Startups might be more likely to form a CVC relationship if there were no outside options. Hence, we control for the relative capital availability of CVCs, measured by the annual inflow of CVC versus VC. However, we do not find that a higher CVC availability relative to VC increases the likelihood of tie formation between a CVC and a startup.

Table 2.6: Likelihood of tie formation for a CVC-startup pair

	Dependent variable: tie formation			
	RE logit	*clustered logit —investor*	*clustered logit —startup*	*GEE*
	(1)	(2)	(3)	(4)
Bottleneck component	0.423**	0.417*	0.417*	0.417**
	(0.171)	(0.239)	(0.240)	(0.182)
Firm age	0.164***	0.162***	0.162***	0.162***
	(0.029)	(0.028)	(0.038)	(0.034)
Connectedness	2.330***	2.320***	2.320***	2.320***
	(0.565)	(0.589)	(0.390)	(0.571)
Trademarks	−0.008	−0.012	−0.012	−0.012
	(0.017)	(0.018)	(0.022)	(0.014)
Patents	0.010**	0.011**	0.011**	0.011**
	(0.005)	(0.005)	(0.005)	(0.005)
Industry overlap	0.311	0.299	0.299	0.299
	(0.201)	(0.271)	(0.348)	(0.206)
Geographical distance	−0.002**	−0.002**	−0.002	−0.002**
	(0.001)	(0.001)	(0.001)	(0.001)
Silicon Valley	0.858***	0.865***	0.865***	0.865***
	(0.165)	(0.230)	(0.226)	(0.170)
Startup experience	0.079	0.077	0.077	0.077
	(0.074)	(0.095)	(0.084)	(0.070)
VC arm	0.374**	0.376**	0.376*	0.376**
	(0.172)	(0.167)	(0.195)	(0.169)
CVC/IVC ratio	1.564	1.660	1.660	1.670
	(2.242)	(3.110)	(3.220)	(2.290)
Constant	−6.151***	−6.200***	−6.200***	−6.200***
	(0.655)	(0.927)	(0.996)	(0.679)
Observations	13,869	13,869	13,869	13,869
Akaike Inf. Crit.	1,668	1,668	1,668	
Note:			*p<0.1; **p<0.05; ***p<0.01	

2.5.1 Robustness checks

Bottleneck measure: Position in a network of components

As a robustness check, we use an alternative approach for determining the bottleneck consisting in obtaining the component with the highest centrality in a network per year. To construct this measure, we first draw a network of components per year. A component is linked to another if an IVC invested in both components in the same year. Then, the nodes correspond to the components, and the links correspond to an IVC common investment in components. We restrict the sample years for this specification from 2014 to 2018, since IVCs did not invest in at least two components in the ecosystem before 2014, which corresponds to 12,765 dyads.

After constructing the network, we rank components according to their centrality. Centrality measures identify the most important nodes in a graph. We identify and select the following centrality measures: Degree centrality classifies the importance of nodes by the number of links or "direct neighbours" in the network. Betweenness centrality classifies nodes by measuring the number of times a node is positioned on the shortest path between other nodes, acting as a "bridge" between them. Closeness centrality, as its name indicates, obtains the "closest" nodes in a network, by calculating length of the shortest paths between nodes, and obtains an importance score based on the sum of its shortest paths. Table 2.7 show the bottleneck components obtained by each of the centrality measures.

Results using this bottleneck approach are portrayed in table 2.8. Similar to the *bottleneck intensity* measure, we observe that for all the centrality measures, the bottleneck variable positively increases the likelihood of two firms to form an investment partnership.

Information Technology vs. Automotive firms' strategies

We presume that established firms have different strategies when directing their CVC investments depending on their main industry of operation. Firms subscribed in the automotive industry are incumbents in car manufacturing activities and have long dynamics in the industry. On the contrary, firms in the information & Technology (IT) industry are entrants in the ecosystem, but have assets that are highly valued for autonomous vehicle manufacturing (i.e. computing,

Table 2.7: Bottleneck components per year in our sample

	2014			2015			2016			2017			2018		
	b	*c*	*d*	*b*	*c*	*s*	*b*	*c*	*d*	*b*	*c*	*d*	*b*	*c*	*d*
LiDar															
Radar															
Camera															
Computer vision				x	x	x	x	x	x				x	x	x
Data & simulation				x	x	x	x	x	x	x	x	x	x		
HD maps	x	x	x												
Localization tech				x	x	x	x	x	x				x		
HMI				x	x	x	x	x	x				x		
V2X															
Software & OS				x	x	x	x	x	x				x		
Cloud															
Teleoperation															
Cybersecurity															

The table indicates the bottleneck component for the betweenness (*b*), closeness (*c*) and degree (*d*) centrality indicators. The bottleneck component is marked with an x for the years of the subsample (2014-2018).

software and data capabilities). This heterogeneity among firms might impact their decision to invest in the bottleneck component. Hence, we perform a robustness check that consists on analyzing separately startup-CVC tie formation, for CVCs in the IT and automotive industry. For that purpose, we subset the sample into two: one containing dyads with CVCs categorized in the "Information & Technology" industry and another containing CVCs in the "automotive" industry.

Table 2.9 contains the results of the models with each subsample. Model 1 is the base model with the entire sample, applying the rare events logistic method. Model 2 is the rare events logistic estimation for the subsample of CVCs belonging to the IT industry. Model 3 is the rare events logistic estimation for the subsample of CVCs belonging to the automotive industry.

Indeed, we find strong differences in the results. IT CVCs are more likely to tie with startups working in the bottleneck component. We do not find the same results for automotive CVCs. This might be because automotive firms might tend to internalize these activities or create non-equity alliances to advance in the bottleneck component. Further studies could analyze the differences.

Table 2.8: Bottleneck measure: position in the network

	Dependent variable: tie formation			
	RE logit	*RE logit betweenness*	*RE logit closeness*	*RE logit degree*
	(1)	(2)	(3)	(4)
Bottleneck component	0.423**	0.3924**	0.423**	0.423**
	(0.171)	(0.191)	(0.209)	(0.209)
Firm age	0.164***	0.1684***	0.163***	0.163***
	(0.029)	(0.029)	(0.029)	(0.029)
Connectedness	2.330***	2.5104***	2.500***	2.500***
	(0.565)	(0.585)	(0.586)	(0.586)
Trademarks	−0.008	−0.016	−0.013	−0.013
	(0.017)	(0.020)	(0.020)	(0.020)
Patents	0.010**	0.0124**	0.012**	0.012**
	(0.005)	(0.005)	(0.005)	(0.005)
Industry overlap	0.311	0.283	0.287	0.287
	(0.201)	(0.211)	(0.211)	(0.211)
Geographical distance	−0.002**	−0.0024*	−0.002*	−0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Silicon Valley	0.858***	0.9514***	0.947***	0.947***
	(0.165)	(0.171)	(0.171)	(0.171)
Startup experience	0.079	0.067	0.065	0.065
	(0.074)	(0.171)	(0.075)	(0.075)
VC arm	0.374**	0.4224**	0.423**	0.423**
	(0.172)	(0.179)	(0.179)	(0.179)
CVC/IVC ratio	1.564	2.390	3.140	3.140
	(2.242)	(2.822)	(2.909)	(2.909)
Constant	−6.151***	−6.4604***	−6.640***	−6.640***
	(0.655)	(0.829)	(0.858)	(0.858)
Observations	13,869	12,765	12,765	12,765
Akaike Inf. Crit.	1,668	1,545	1,545	1,545
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 2.9: Information and technology vs. automotive firms

	Dependent variable: tie formation		
	RE logit	*RE logit Inftech*	*RE logit Automotive*
	(1)	(2)	(3)
Bottleneck component	0.423**	0.677**	0.044
	(0.171)	(0.315)	(0.323)
Firm age	0.164***	0.191***	0.122**
	(0.029)	(0.048)	(0.054)
Connectedness	2.330***	2.326**	2.306**
	(0.565)	(1.016)	(1.094)
Trademarks	−0.008	0.006	−0.046
	(0.017)	(0.030)	(0.044)
Patents	0.010**	0.008	0.009
	(0.005)	(0.009)	(0.009)
Industry overlap	0.311	0.638**	0.269
	(0.201)	(0.303)	(0.402)
Geographical distance	−0.002**	−0.001	−0.003*
	(0.001)	(0.002)	(0.002)
Silicon Valley	0.858***	0.490	1.115***
	(0.165)	(0.310)	(0.288)
Startup experience	0.079	0.082	0.172
	(0.074)	(0.135)	(0.113)
VC arm	0.374**	0.885***	0.219
	(0.172)	(0.324)	(0.278)
CVC/IVC ratio	1.564	0.015	15.058***
	(2.242)	(4.007)	(5.241)
Constant	−6.151***	−6.338***	−9.447***
	(0.655)	(1.189)	(1.550)
Observations	13,869	4,422	4,422
Akaike Inf. Crit.	1,668	504	607

Note: *p<0.1; **p<0.05; ***p<0.01

2.6 Conclusion

In nascent innovation ecosystems, established firms are interested in resolving bottlenecks, as they constrain the growth and success of the ecosystem. Scholars have recently studied some of the mechanisms used by firms to lift bottlenecks in ecosystems, such as reallocating innovative efforts in the form of patenting, widening capabilities, or internal corporate venturing (i.e. intrapreneurship). We contribute to this literature by adding that firms also use corporate venture capital investments for that purpose. We explored this question in the context of the autonomous vehicle ecosystem.

Our findings indicate that established firms with CVC programs allocate their investments in startups producing bottleneck components, This is specially the case for firms in the IT industry. These results highlight the cooperative dynamics between established firms and startups in an ecosystem context; that is, for a focal product to be developed, firms involved in the ecosystem cooperate among them a resolve the potential constraints that could slow or hinder the development of the focal product. However, competitive efforts are also present in an ecosystem context, as we could observe the presence of the "swimming with sharks" dilemma. Indeed, startups acknowledge the risk of misappropriation of their innovation from corporate investors and recur to formal and informal IP protection. Some of the informal mechanisms used are partnering when the innovation is more mature and the startup is more stable (i.e. timing defenses), and connections to influential third parties (i.e. social defenses), while the formal mechanism used is patenting.

Our study expands the understanding of inter-firm relationships to the ecosystem context, by investigating the unexplored interplay between ecosystems and corporate venture capital. Our findings have implications for incumbent firms and start-ups willing to collaborate in an innovation ecosystem. Established firms use CVC investments as a strategic tool to enter ecosystems and cooperate with startups developing bottleneck components of the focal product. However, competitive traits also emerge as startups acknowledge the risks of entering investment partnerships and protect themselves against IP misappropriation.

2.6.1 Limitations

While our work provides insights to the academic literature, we acknowledge some limitations. The first limitation is that, while we identify a greater likelihood of CVC firms to invest in start-ups producing components that are considered bottlenecks at any point in time, our data does not allow us to understand to which extent the investments help resolving the bottleneck. We leave this question to future work.

It is possible that incumbents have used CVC to approach new firms so they can vertically integrate with the new firm through an acquisition, entering the bottleneck component. This is a strategy Hannah and Eisenhardt (2018) identified in the solar photovoltaic panel ecosystem. In our data, however, we cannot identify it. We also cannot identify whether and to which extent CVC investors learn about the component through the CVC and imitate the new firm.

CHAPTER 3

THE RELATIONSHIP BETWEEN PUBLIC CHARGING INFRASTRUCTURE DEPLOYMENT AND OTHER SOCIO-ECONOMIC FACTORS AND ELECTRIC VEHICLE ADOPTION IN FRANCE

Bassem Haidar[1] and Maria Teresa Aguilar Rojas[2 3 4]

Abstract

Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) offer a promising choice to replace fossil-fuel dependent Internal Combustion Engine Vehicles (ICEVs) with a low-emission transport solution. Governments, automotive manufacturers, and charging infrastructure operators have deployed market-boosting initiatives to incentivize purchase. Yet, their market diffusion is limited by several barriers. To shed light on the main barriers, and based on an extensive state-of-the-art, we used an original database and statistically analyzed the relationship of 21 socio-demographic, technical, and economic factors on BEV and PHEV market shares, separately, in 94 French departments from 2015 to 2019, using mixed-effect regression. We find different covariates related to BEV and PHEV sales, respectively, suggesting the two markets respond to different incentives. The number of available BEV/PHEV models and energy prices are positively correlated with BEV and PHEV adoption. Fast, ultrafast charger density and local incentives positively relate with BEV sales, while slow-and-normal charger density to PHEV sales. Contrarily, national subsidies, relative to vehicles' prices, are negatively correlated with PHEVs sales and is open for further studies. Based on the results, policy recommendations are considered for the automotive industry, charging operators, and local authorities to draw a roadmap for electric mobility transition in France.

Keywords: Charging Infrastructure, Electric Vehicle, Incentives, Mixed-Effects Modelling, Technology Adoption

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[1]Université Paris-Saclay, CentraleSupélec, Laboratoire Genie Industriel

[2]University Paris-Dauphine (PSL), Governance and Regulation Chair, M&O Laboratory

[3]This paper is under submission. The final version may be different to the one presented in this thesis.

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3.1 Introduction

Greenhouse gas (GHG) emissions contribute to the climate change phenomenon. France has set the ambitious goal to reduce CO2 emissions and the dependency on petroleum products by 40% by 2030, with respect to the emissions level in 1990, and ban high-emission vehicles by 2030 (French National Assembly, 2021). Plug-in Electric Vehicles (PEVs) have noteworthy potential to reduce petroleum dependency and GHGs emissions related to the road transportation sector towards global decarbonization (Hainsch et al., 2021). PEVs encompass Battery Electric Vehicles (BEV), which use the electricity stored in the battery as a primary energy source, and Plug-in Hybrid Electric Vehicles (PHEV), which use both fossil fuel and battery as sources of energy. If the electricity is produced using renewable energy sources, the GHG emissions from transportation are significantly lower than fossil-fuel based transport. While this technology's adoption has been rapidly increasing over the last decade, its market share remains restrained by socio-techno-economic barriers (Egbue & Long, 2012). The reasons for the slow uptake of PEVs compared to ICEVs are generally divided into technical (long charging duration, limited BEV range), economic (PEV purchase, electricity, and fuel prices), awareness (client behaviour towards new inventions, charging stations visibility, number of PEV models), and socio-demographic factors (age, education, income, environmentalism, and urbanity degree) (Egbue & Long, 2012; Javid & Nejat, 2017; Sierzchula, Bakker, Maat, & Van Wee, 2014; Tran, Banister, Bishop, & McCulloch, 2012). To overcome these obstacles, governments applied national and local, monetary, and non-monetary policies for all the PEV supply chain members (Sykes & Axsen, 2017).

PEVs presented around 4% of France's total vehicle sales until 2020 (French Ministry of Ecological Transition, 2020). France adopted several laws to reduce fossil-fuel dependency, such as the Provisions of the Energy Transition Law for Green Growth and the Mobility Orientation Law (French Ministry of Ecological Transition, 2021). Increasing fossil-fuel prices, a statute in these laws, proved to be a solution that pushes drivers to switch from ICEVs to PEVs in several countries (S. Li, Tong, Xing, & Zhou, 2017; Plötz, Gnann, & Sprei, 2016). However, it led to the Yellow Vests social movement, pushing the French government to search for other solutions to accelerate the electric mobility transition. Meanwhile, local authorities, such as municipalities at Ile-de-France, Marseille, and Nice, contributed to making EVs more attractive to consumers by offering financial subsidies of a maximum of 5000€ to each driver switching to electric mobility to tax exemption, free parking, and access to bus lanes. Since the lack of charging infrastructure still presents a barrier to growth in the PEV market, as the driver suffers from range anxiety –the fear of a blackout in the middle of the road– national and local authorities in France boosted the deployment of this infrastructure by both installing more public chargers (e.g. Corri-door project (EC, n.d.)) and offering up to 50% of the cost of the charger for both private and public usage (e.g. ADVENIR project (project Advenir, 2020)). In sum, the French government allocated 100 million euros to finance more than 45,000 new charging points by the end of 2023 (project Advenir, 2020).

Investigating the key factors that are interconnected with BEV and PHEV uptake is crucial to accelerating the French electric mobility transition. Several studies evaluated the relationship between socio-techno-economic factors and the PEV purchasing activity using empirical methods, such as Vergis and Chen (2015) in the U.S., Wang, Pan, and Zheng (2017) in China, Mersky et al. (2016) in Norway, and Münzel et al. (2019) for a global review. Yet, several factors are still unexplored in the existing literature. First, as the influence of market-booster factors differs significantly between countries due to different consumer behaviours (Münzel et al., 2019), the French local-based case study is still lacking and needs to be considered to help the government attain ambitious national targets. Second, while the study on the influence of government policies has received widespread attention in the literature (Hardman, 2019; Jenn, Springel, & Gopal, 2018; Münzel et al., 2019), the link between purchasing subsidies and PEV sales is analyzed in the literature as a constant variable. Indeed, an adjustable measure of subsidies concerning the price of the purchased vehicle is still lacking, as the vehicle's investment is essential to capture the battery packs' cost variation. Third, charging infrastructure proved to be an essential factor in boosting PEV markets (X. Li, Chen, & Wang, 2017; Plötz et al., 2016). Still, the literature considered charging infrastructure as one covariate and failed to mention that different charging speeds are available. Therefore, the potential impact of different-power charging infrastructure on BEV/PHEV demand is still missing (Morganti, Boutueil, & Leurent, 2016). Fourth, previous studies did not include a variable describing a vehicle's electric range, which could be an essential factor in solving the range anxiety problem, especially for BEV drivers and understanding the customers' choice towards different-size vehicles. The novelty of our study will be to: (1) consider the department-level French case, (2) study the relationship between several new covariates (different-power charging infrastructure deployment, the French department-level subsidies concerning the vehicle's price, the vehicle's electric range) with BEV and PHEV sales. We also contribute to the scarce literature, only considered in (Vergis & Chen, 2015), that suggests BEV and PHEV markets respond to different market shares' boosting strategies by evaluating how the studied factors vary between the two markets.

This paper seeks to fill these gaps by assessing the privately-purchased BEV and PHEV market shares, separately, using a mixed-effects regression on a local level in France from 2015 to 2019, taking into account the charging infrastructure deployment of different power speeds and other socio-economic factors. The data of these 21 covariates were gathered from various governmental and press sources and allowed us to build an original and recent database of 94 French states spanning five years. These covariates could vary within three dimensions: the French-local level, the year, and EV type. To the best of our knowledge, our study is the first to isolate the impacts of local-level incentives regarding the vehicle's price, the vehicle's electric range, and four charging powers on the adoption rate of BEVs and PHEVs separately in France. Also, our work differs from existing studies in using mixed-effects regression that captures the effect of time-variant and constant covariates. It should be noted that methods applied in our study could help the French government build a clear roadmap for electric mobility transition by identifying the market-booster factors and concluding with policy recommendations rather than definitive causation.

The rest of this paper is organised as follows. Section 3.2 presents an extensive overview of econometrics studies on PEV adoption. In Section 3.3, we describe the data and methodology. Section 3.4 details the BEV and PHEV models' regression results and policy recommendations, followed by robustness checks in Section 3.5. Conclusions are provided in Section 3.6.

3.2 Literature review

Based on academic-published papers focusing on PEV adoption in different countries and periods, this section identifies the candidate variables that could boost the market. We will neglect other research papers focusing on AFVs (HEV, FCEV)[5]. Figure 3.1 summarises the discussed papers, their case studies (countries, period), methodologies, datasets, and the used control variables.

Sierzchula et al. (2014) analyzed the relationship between governmental incentives, socio-economic factors, and 30 national electric-vehicle market shares in 2012, using a country-based multiple linear regression analysis. They found financial incentives, charging infrastructure, and the local presence of production facilities to significantly affect a country's electric vehicle market share. Results suggest that charging infrastructure was the most decisive related factor to electric vehicle adoption. However, they pointed out that neither financial incentives nor charging infrastructure could ensure high electric vehicle adoption rates. Plötz et al. (2016) analyzed country-based market shares of BEV and PHEV market shares in different European countries and state-based PEV stock in the United States using a Pooled OLS regression with data from 2010 to 2014. Their results show that economic factors such as income and gasoline prices are mandatory in analyzing policies since they could explain PEV adoption rates variance. Besides, both direct and indirect incentives positively affect PEV adoption, based on empirical PEV market data from the U.S. and Europe. They concluded that the effects of different factors, such as the electricity price and public charging infrastructure, remain open for further research.

Another group of publications used the stepwise linear regression[6] to analyze the PEV adoption. Mersky et al. (2016) analyzed the impact of socio-demographic factors (population, average kilometres travelled), economic factors (income), and EV infrastructure (number of charging points) on the BEV yearly sales in Norway from 2010 to 2013 on both regional and municipal level. Since data was unavailable, the authors excluded financial incentives (tax benefits) and non-financial incentives (free parking) offered on a national level. Results showed that

[5] AFV: Alternative Fuel Vehicle; HEV: Hybrid Electric Vehicle (could not be charged using an external charger); FCEV: Fuel Cells Electric Vehicle.

[6] It should be noted that stepwise linear regression has been criticized for yielding over-confident predictors (Harrell, 2001; Münzel et al., 2019).

charging infrastructure is the most powerful predictor for BEV sales share. Wang et al. (2017) explored the key factors that promote EVs using a Partial Least Squares structural equation analysis to analyze the BEV and PHEV city-level sales in China, considering incentive measures and socio-demographic data between 2013 and 2014. Results show that the density of charging infrastructure, license fee exemption, no driving restriction, and priority to charging infrastructure construction lands are the four most important factors to promote EVs. This paper recommends that local municipalities or governments should strengthen the charging infrastructures as preferential policy by solving the problems related to civil construction, grid connections, and smart grids. Vergis and Chen (2015) examined the correlation between social, economic, geographic, and policy factors on BEV and PHEV adoption across U.S. states in 2013. After applying a stepwise regression on state-level PEV market shares, their results showed that the significant variables are the consumer attribute variables (education, awareness of electric vehicles), geographic variables (average winter temperature, population density), variables related to the cost of energy (gasoline and electricity costs) and the ability to access charging infrastructure away from home. The variables that are significantly correlated with PHEV market shares are market characteristics (the number of available PHEV models), incentives (financial and non-financial incentives), and average winter temperatures.

The third group of papers took advantage of their data's panel structure and built a panel data regression considering the temporal evolution. Gallagher and Muehlegger (2011) applied time and state fixed effects on BEV sales per capita on a quarterly U.S. state-level from 2000 to 2006, taking into account different socio-demographic (mean age, female percentage, education level), and economic (income, gasoline prices, incentives) variables. They found evidence that hybrid vehicle adoption is positively affected by incentives, income, and gasoline prices. Clinton and Steinberg (2019) applied the same model by adding charging infrastructure and electricity price covariates on the BEV sales per capita of the U.S. states between 2010 and 2015. Their findings indicate that incentives offered as state income tax credits do not significantly affect BEV adoptions. Jenn et al. (2018) found that financial incentives have a significant and positive effect on PEV sales after analyzing monthly U.S. state-level data for 2010 to 2015, including fixed effects for time-varying, regional, and vehicle model-specific factors, using a

Generalized Method of Moments (GMM) to estimate their regression. Also, they included a lagged-dependent variable to account for suspected endogeneity in their model. Wee, Coffman, and La Croix (2018) analyzed semi-annual state-level newly registered EV by make, from 2010 to 2015, and state-level policies using a panel data regression. They pointed out that an additional 1000€/BEV of subsidies could increase sales by 5 to 11%. Based on quarterly EV sales and charging station deployment in 353 metropolitan areas in the U.S. from 2011 to 2013, S. Li et al. (2017) found that sales incentives substantially affect EV sales. Also, results showed that the effect would be more significant if the subsidy had been directed toward charging infrastructure instead. Soltani-Sobh, Heaslip, Stevanovic, Bosworth, and Radivojevic (2017) conducted a cross-sectional/time–series panel analysis on the EV sales in the U.S. from 2003 to 2011, using socio-demographic (degree of urbanity, vehicle mileage travelled) and economic (income, gas prices, electricity prices, financial incentive) factors. The results showed that electricity prices were negatively associated with EV adoption, while urban roads and government incentives positively affected states' electric vehicle market share. Using a fixed-effects regression model, X. Li et al. (2017) studied the impacts of seven factors on EV densities from fourteen countries between 2010 and 2015. The authors found that the percentage of renewable energies in electricity generation, the number of charging stations, the education level, the population density have apparent and positive impacts on the demands, contrary to the GDP per capita and urbanization. The gasoline price affects the demands for BEVs more than that for PHEVs. Münzel et al. (2019) reviewed econometric studies on the effect size of purchase incentives and analyzed data on PEV sales from 32 European countries from 2010 to 2017 using panel data regression. They used as control variables both monetary and non-monetary incentives, socio-economic variables, such as electricity and diesel prices, and slow and fast charging infrastructure. They found that energy prices and financial incentives influence PEV adoption positively.

We completed and adapted the literature review provided by Münzel et al. (2019) in Table 3.1, by adding the articles of (X. Li et al., 2017; Münzel et al., 2019; Soltani-Sobh et al., 2017), by considering only academic-published articles, and by eliminating the articles discussing the evolution of HEVs and FCEVs. We found that the independent variable is generally measured by the PEV market share and is analyzed using various econometric methods: OLS, panel, and stepwise regressions. Various social, demographic, economic, and technical covariates were used, primarily monetary and non-monetary incentives, income, energy prices, population density, and charging infrastructure deployment. As it can be seen in Table 3.1, the studied covariates do not share the same significance level on the PEV sales since it is highly dependent on the year of study, the spatial resolution (national or local analysis), the owners' driving behaviour, and the technological progress of PEV. Therefore, general conclusions could not be transferred to the French local-based case study without a detailed market analysis.

While many articles in the literature zoomed into the relation of various covariates with PEV shares, the research gaps, which we will try to fill in this paper, remain on: (1) including other factors, such as different-power charging infrastructure deployment, the French department[7]-level subsidies concerning the vehicle's price, the vehicle's electric range, (2) evaluating how the studied factors vary between the BEV and PHEV markets, and (3) concentrating on the case of France. Moreover, here we apply a mixed-effects regression method, which was not considered in the existing studies - as we are aware - that captures the effect of both time-variant and constant covariates. As a final step, regression results are used to conclude with policy recommendations for the EV ecosystem members: the automotive manufacturer, the charging operator, and public authorities.

[7] In the administrative divisions of France, the department (département) is one of the three levels of government under the national level, between the administrative "regions" and the "communes". France is composed of 13 regions, 95 departments (94 in metropolitan France (in French, *France métropolitaine*) and Corsica), and 34670 communes.

Author (Year)	Observations	Time resolution	Vehicle Type	N	Method	Dependent variable	Covariates															
							Financial incentives	Non-Financial incentives	Charging infrastructure (Private)	Charging infrastructure (Public)	Vehicle price	Income	Education	Gasoline price	Electricity price	Population density	Mileage	Unemployment rate	Percentage of female	Environmentalism	Number of available vehicles models	Renewable Energy production
Clinton & Steinberg (2019)	United States (State level)	2010-2015, Monthly	BEV	3864	Fixed Effect panel data regression	Sales per capita	NA	-	+	+		+	+	+	-				+	+		
Jenn et al. (2018)	United States (State level)	2010-2014, Quarterly	PEV	18644	Fixed Effect panel data regression/LDV Model with GMM estimator	Absolute sales	NA	NA														
Gallagher & Muehlegger (2011)	United States (State level)	2000-2006, Quarterly	PEV	4630	Fixed Effect panel data regression	Sales per capita	+					+	+	+					+			
Li et al. (2017)	United States (Metro areas)	2011-2013, Yearly	PEV	14563	OLS and GMM regressions	Absolute sales	+		+	+		+		+						+		
X. Li et al. (2017)	14 countries	2010 to 2015, Yearly	PHEV, BEV	84	Fixed Effect panel data regression	EV density				+		NA	+	+		NA						+
Mersky et al. (2016)	Norway (Municipality level)	2000-2013, Yearly	BEV	163/20	Stepwise linear regression	Sales per capita	0	+	+	+		NA					-	NA				
Munzel et al. (2019)	A global review and 32 European countries	2010 to 2017, Yearly	PEV	189/226	Fixed Effect panel data regression	Sales share	+					+		-	+							
Plotz et al. (2016)	12 European countries and the United States	2010-2014, Yearly	PEV	35/125	Pooled OLS regression	Sales share and Stock per capita	NA	+		+		NA		+	-							
Sierzchula et al. (2014)	30 countries	2012, Yearly	PEV	30	Pooled OLS regression	Sales share	+			+	+	-	+	-	-	+				+	+	
Soltani-Sobh et al. (2017)	United States (State level)	2003 to 2011, Yearly	PEV	171	Fixed and random effect panel data regression	Sales share	+					+		+	-	+	+					
Vergis & Chen (2015)	United States (State level)	2013, Yearly	PHEV, BEV	50	Stepwise linear regression	Sales share	+	+		+			+	+	-	+	-			+	+	
Wang et al. (2017)	China (City level)	2013-2014, Yearly	PHEV, BEV	41	Stepwise linear regression	Sales per capita	0	0		+		0										
Wee et al. (2018)	United States (State level)	2010-2015, Yearly	PHEV, BEV	1952-4287	Multi-level Fixed Effect regression	Absolute sales	+	-		-		+		+	-	+	+					

« + » positive impact, « - » negative impact, « NA » Not Available impact, « 0 » not reported
Colors indicate the significance level: 'light grey': low significance, 'grey': modest significance, 'dark grey': high significance, 'white': no significance
Adapted from: (Münzel et al., 2019) by adding the articles of (X. Li et al., 2017; Münzel et al., 2019; Soltani-Sobh et al., 2017) and by eliminating the articles discussing the evolution of Hybrid EV (HEV) and Flex-Fuel Vehicles (FFV).

Figure 3.1: A selection of econometric studies presented in the literature review (adapted from (Münzel et al., 2019))

3.3 Data and methodology

3.3.1 Data

To estimate the relationship of different socio-techno-economic factors on the French BEV and PHEV market shares, we collected this dataset from different governmental sources and press articles sources for the 94 French departments from 2014 to 2019. It should be noted that we discarded five overseas departments[8] and the island of Corsica. Table 3.1 contains the summary statistics of the data used in our study, the sources, and the name and description of the variables used in the model.

Dependent variable: BEVs and PHEVs market shares

To address the PEV sales, we used BEVs and PHEVs yearly privately-purchased, neglecting other types of vehicles, car registration shares of 94 departments in France from 2015 to 2019 (French Ministry of Ecological Transition, 2020). The collected dataset is balanced without missing values in any years and departments[9]. Figure 1 in Appendix A summarises both BEV and PHEV market share evolutions in the French departments from 2015 to 2019. The BEV market share's growth from 2015 to 2019 varies from 1% to more than 12%, and for the PHEV, market share fluctuates from 0% to more than 7%.

Technical factors

To investigate the effect of the recent deployment of public charging infrastructure on PEV adoptions, we collected the number of semi-public and public chargers per department and per power from the official French data website (data official site, 2020). Since the installation date for every charging station is unavailable, we conducted a backward evolution trend of the infrastructure deployment from 2014 to 2018 by applying the percentage increase collected from (EAFO, 2020) equally to these departments. Chargers with 3-7 kW power are considered slow chargers, 22 kW as normal, between 50 kW as fast, and more than 150 kW as ultra-fast.

[8]The five overseas departments (in French, *départements d'outre mer*) excluded from our study are the islands of Guadeloupe, Martinique, Mayotte, La Réunion, and the French Guiana.

[9]It should be noted that no PHEV sales were recorded in the department number 48 in 2016.

The results section should note that chargers with different powers do not share the same price, charging tariffs, or availability. Also, the charging tariffs depend on the charging operator. Table 3.2 details the charger's price, the tariffs, and the charging durations and fees for a 50-kWh BEV and a 17-kWh PHEV. It should be noted that most PHEVs are not compatible with fast and ultra-fast charging technology (Fastned, 2021).

					50 kWh BEV		*17 kWh PHEV*	
Charging speed	**Charging power**	**Charger's price**	**Availability**	**Charging pricing system**	**Charging duration**	**Charging fees**	**Charging duration**	**Charging fees**
Slow charger	3-7 kW	2000€	At-home, on-street (*Cities*)	1 €/hour sometimes free	11 hours	11 €	4 hours	4 €
Normal charger	22 kW	4000€	On-street, points of interest (supermarkets), (*Cities*)	1.5€/first hour 0.2€/min after	2.7 hours	20 €	0.9 hours	1.2 €
Fast charger	50 kW	25000€	On-street, points of interest (supermarkets), (*Cities*)	2€/access 0.4€/min	1.2 hours	25 €	Not compatible	
Ultrafast charger	150 kW	40000€	Highways	4€/access 0.8€/min	0.4 hour	30 €	Not compatible	

Figure 3.2: Charging costs of different charging powers (Chargemap, 2022)

Data on installed private chargers per department is unavailable. To evaluate the relationship of private charging with electric vehicle purchase, we use the proportion of households with at-home parking as a proxy (INSEE, 2017). Households with parking spaces are more likely to have a private charger for PEVs than those without parking.

Finally, we included a variable describing the average electric range of sold BEV and PHEV models per department and per year, derived from the onboard battery, to explain adopters' range anxiety issues. Indeed, a vehicle's electric range is influenced by various factors, such as the vehicle's weight and the driving behaviour (i.e. driving speed, number of stops, and weather conditions) (Sweeting, Hutchinson, & Savage, 2011). We gathered the vehicles' electric range in WLTP[10] worldwide standards from the brands' official websites. The range provided by the fuel tank of a PHEV is not considered. Indeed, BEVs' electric ranges are higher than those of PHEVs.

[10]World harmonized Light-duty vehicles Test Procedure

Table 3.1: Summary statistics of covariates

Variable	Variable description	Years	Unit	N	Mean	St. Dev.	Min	Max	Sources
				Dependent variables					
$\mathbf{PEV}_{\mathrm{msBEV}}$	BEV market share	2015-2019	%	470	0.014	0.005	0.002	0.045	(French Ministry of Ecological Transition, 2020a)
$\mathbf{PEV}_{\mathrm{msPHEV}}$	PHEV market share	2015-2019	%	470	0.004	0.003	0.0004	0.023	
				Socio-demographic Covariates					
$\mathbf{d}_{\mathrm{population}}$	Population density	2015-2019	People/km²	470	592.696	2,461.916	15	21014	(INSEE, 2020a)
$\mathbf{p20-39}$	The percentage of the population aged between 20 and 39	2015-2019	-	470	0.22	0.031	0.168	0.337	(INSEE, 2020b)
$\mathbf{p40-59}$	The percentage of the population aged between 40 and 59	2015-2019	-	470	0.266	0.008	0.243	0.284	(INSEE, 2020b)
unemployment$\mathbf{t}_{\mathrm{rate}}$	Unemployment rate	2015-2019	-	470	9.141	1.871	5.05	15.525	(INSEE, 2020c)
VKT	Vehicle Travelled Kilometres	2019	km	470	12.734	2.764	7	20	(ENTD, 2019)
Two vehicles	The proportion of households with two vehicles	2018	%	470	37.961	6.567	4.1	47.3	(INSEE, 2018b)
Education	The proportion of people who finished a minimum of a bachelor's program	2018	%	470	0.142	0.027	0.102	0.267	(INSEE, 2018a)
Emissions	pm10, pm25, CO, NOx, SO2, C6H6, COVNM, and NH3 emissions per capita	2016	kg/capita	470	98.686	43.118	7.905	240.042	(French data official site, 2018; INSEE, 2020b)
SolarProduction	Low voltage solar energy production per capita	2015-2019	MWh/capita	470	0.19	0.281	0.001	1.758	(French data official site, 2022; INSEE, 2020b)
Parking at home	The proportion of households with at-home parking	2017	%	470	0.794	0.539	0.001	2.4	(INSEE, 2017)
Female	The proportion of females in the population	2015-2019	-	470	51.462	0.5	49.97	52.95	(INSEE, 2020b)
				Availability Covariates					
nb models$_{\mathrm{BEV}}$	Number of available BEV models	2015-2019	-	470	21	4,152	18	29	(Avem, 2020)
nb models$_{\mathrm{PHEV}}$	Number of available PHEV models	2015-2019	-	470	28.2	12.573	16	52	(Avem, 2020)
				Economic Covariates[11]					
subsidies$_{\mathrm{BEV}}$	Subsidies for purchasing a BEV	2015-2019	€	470	691.489	1,463.680	0	5,000	(Automobile Propre, 2020; Beev, 2019; Charente Libre, 2016; CompteCO2, 2015; Nicematin, 2017)
subsidies$_{\mathrm{PHEV}}$	Subsidies for purchasing a PHEV	2015-2019	€	470	345.745	731.840	0	2,500	

[11]The deflator is considered in the economic covariates.

Table 3.1: Summary statistics of covariates

Variable	Variable description	Years	Unit	N	Mean	St. Dev.	Min	Max	Sources
$\text{price}_{\text{BEV}}$	Average price of the most sold BEV	2015-2019	€	470	38,480.07	1,853.241	23,250	40,030	(Automobile Propre, 2015; Elite Auto, 2015; La Revue Automobile, 2015; L'Argus, 2015a)
$\text{price}_{\text{PHEV}}$	Average price of the most sold PHEV	2015-2019	€	469	49,772.340	14,020.320	26,100	111,902	
$\text{diff}_{\text{taxes}}$	Difference in registration taxes	2015-2019	€	470	36.019	14.298	0	51.2	(Le Figaro, 2019, 2018, 2017, 2016, 2015)
$\mathbf{p}_{\text{gasoline}}$	Gasoline price (SP95)	2015-2019	€/l	470	1.435	0.085	1.302	1.759	(French Ministry of Economy and Finance, 2020)
$\mathbf{p}_{\text{electricity}}$	Electricity price	2015-2019	€/kWh	470	0.174	0.005	0.168	0.180	(French Ministry of Ecological Transition, 2020b)
income	Average amount of income declared per household	2014-2018	€	470	24,815.910	3,835.549	19,249	44,794	(French Ministry of Economy and Finance, 2020b)
$\text{Bonus}_{\text{BEV}}$	National-level bonus for purchasing a BEV	2015-2019	€	470	6120	147.126	6000	6300	(Automobile Propre, 2019, 2018, 2016; L'Argus, 2015b; Leparticulier, 2017)
$\text{Bonus}_{\text{PHEV}}$	National-level bonus for purchasing a PHEV	2015-2019	€	470	1600	1357.911	0	2000	(Automobile Propre, 2019, 2018, 2016; L'Argus, 2015b; Leparticulier, 2017)
Technical Covariates									
$\mathbf{d}_{\text{slow chargers}}$	Slow chargers density	2014-2018	charger/km²	470	0.104	0.791	0.001	11.61	(EAFO, 2020; French data official site, 2020)
$\mathbf{d}_{\text{normal chargers}}$	Normal chargers density	2014-2018	charger/km²	470	0.034	0.114	0.001	1.381	(EAFO, 2020; French data official site, 2020)
$\mathbf{d}_{\text{fast chargers}}$	Fast chargers density	2014-2018	charger/km²	470	0.002	0.006	0	0.076	(EAFO, 2020; French data official site, 2020)
$\mathbf{d}_{\mathbf{ultra-fast\ chargers}}$	Ultra-fast chargers density	2014-2018	charger/km²	470	0.001	0.006	0	0.090	(EAFO, 2020; French data official site, 2020)
$\text{electric range}_{\text{BEV}}$	BEV electric range	2015-2019	km	470	150.283	4.354	150	243	Own sources and Official brands websites
$\text{electric range}_{\text{PHEV}}$	PHEV electric range	2015-2019	km	469	39.365	9.985	22	66	

Economic factors

Several economic factors could stimulate PEV purchasing activity. First, financial incentives, such as local subsidies, could help overcome the vehicle's high cost (Sierzchula et al., 2014). Information on French-local subsidies was gathered from departments and municipalities' websites and press reviews. These local subsidies, which are fixed for all vehicles' prices, vary between 0€ and 5000€ for BEV and between 0€ and 2500€ for PHEV, based on the department and the year. Indeed, the ratio of subsidies concerning the vehicle's investment could vary. For instance, regarding BEVs, the purchasing price of a Renault Zoé (52 kWh) is 32000€ compared to 45000€ for a Tesla Model 3 (75 kWh). Regarding PHEVs, a BMW Serie 2 (7.6 kWh) purchase price is 45000€ compared to 90000€ for a Porsche Cayenne (14.1 kWh). Hence, we considered the ratio of subsidies over the price of the most sold vehicle in each department and each year. We included the price of the most sold vehicle per department and per year, similarly to Sierzchula et al. (2014). Prices were gathered from different press articles (i.e. Automobile Propre (2015, 2016, 2018, 2019, 2020); Elite Auto (2015); La Revue Automobile (2015); L'Argus (2015a, 2015b)).

We also account for financial incentives at the national level, which are revised and adjusted each year. A vital policy to encourage PEV purchase and discourage ICEV purchase in France is the "*Bonus-Malus*". The policy has two components. On one side, buyers can benefit from a national subsidy, called the *bonus*, to purchase low-emitting vehicles, notably PEVs. The bonus differs between BEVs and PHEVs, and it varies with respect to the price of the vehicle, until a certain cap. Vehicles with a price higher than 60000€ are not concerned by the bonus. On the other side, buyers can be charged with a *malus*, which takes the form of a tax, that varies concerning the vehicle's characteristics. If the level of CO2 emissions exceeds a specific limit, a tax is added to the registration certificate. Therefore, we account for the bonus amount relative to the price of the most sold vehicle in each department per year. We do not consider the amount of malus due to the lack of data on the most sold ICEV vehicle.

Additionally, BEVs are exempt from either 50% or 100% of the total registration fee in specific departments during this study period. We collected the difference between BEV and ICEV registration fees from press articles (Le Figaro, 2015, 2016, 2017, 2018, 2019). This difference captures the monetary savings in taxes of a BEV compared to an ICEV. Registration fee exemption for PHEV adopters depends on the emissions cap of each vehicle. Since we do not know the distribution of PHEVs exempted per department, we decided not to consider this incentive. No reliable source was found for other local monetary and non-monetary incentives (free parking, access to restricted traffic sones, access to bus lanes), making it impossible to include them in our study.

Previous research indicates that energy costs played a crucial role in boosting PEV purchasing activity and were found to affect switching into electric mobility (Gallagher & Muehlegger, 2011; S. Li et al., 2017; Plötz et al., 2016; Vergis & Chen, 2015). A high electricity cost discourages PEV purchase, while a high gasoline price does the opposite. To obtain the relative gain in energy prices, we compute the ratio between electricity and gasoline prices. We obtained the yearly-average electricity and gasoline prices per department using daily gasoline prices and yearly national-electricity prices for the studied period (French Ministry of Economy and Finance, 2020a).

Additionally, we grouped the average amount of income declared per household to the tax authorities from 2014 to 2018 (French Ministry of Economy and Finance, 2020b), according to existing literature (Gallagher & Muehlegger, 2011; S. Li et al., 2017).

Finally, to adjust for the effects of inflation/deflation during our analysis period, we divided all the economic covariates by the GDP deflator by considering 2015 as the base year (World Bank, 2020)[12].

Socio-demographic factors

As described in the literature review section, socio-demographic factors could influence the adoption of PEVs, namely age, sex, education level, population density, and environmentalism (Clinton & Steinberg, 2019; S. Li et al., 2017; Soltani-Sobh et al., 2017; Vergis & Chen, 2015). Thus, we obtain official socio-demographic data for every department: the population density (INSEE, 2020c), the percentage of the population having the minimum legal driving

[12]The GDP deflator measures the change in prices for all goods and services in an economy. Constant prices are obtained by dividing nominal prices (the prices in a given year) to the GDP deflator (for a base year). Then, constant prices reflect the value of goods, with respect to a base year, correcting by the effects of inflation.

age (between 19 and 59) (INSEE, 2020b), the average unemployment rate (INSEE, 2020d), the proportion of the population who obtained at least a bachelor's degree (INSEE, 2018b) and the percentage of female in the population (INSEE, 2020b).

To evaluate the link between drivers' daily trip's needs and the BEV and PHEV purchasing sales, we added a covariate that measures the average-daily vehicle travelled kilometres (home-work trips) of the drivers living in the department (ENTD, 2019).

Besides, we included a public availability factor, measured by the number of available BEV and PHEV models, which could significantly impact the PEV sales (Sierzchula et al., 2014; Vergis & Chen, 2015).

We add the proportion of households in a department with two vehicles (INSEE, 2018a) (INSEE, 2018b). Studies suggest that the electric vehicle is not usually the first car in a household (Lepoutre, Perez, & Petit, 2019). BEV purchasers tend to own at least two vehicles; an ICEV used for long-distance trips and the BEV used for short distance purposes, such as daily commutes.

Intrinsic environmental preferences might motivate the decision of users to purchase PEVs over ICEV. Thus, we control environmentalism in a department by using two measures as a proxy. The first one is the level of emissions[13] per capita in a department. Departments with higher emissions might negatively correlate with the level of concern for environmental issues. A second measure is the amount of solar energy production per capita. Higher solar energy production in a department indicates the willingness to switch to cleaner energy production modes. In addition, this measure indicates the level of energy decentralization in a department since people might behave as energy prosumers by using solar panels to recharge their batteries (data official site, 2018).

3.3.2 Methodology

Based on the literature, we chose the mixed-effects regression to analyse PEV adoption. Mixed-effects are an extension to linear models since they incorporate both fixed and random effects. Predictors in the model are considered fixed effects, while grouping variables are random effects

[13]Emissions included in our study are pm10, pm25, CO, NOx, SO2, C6H6, COVNM and NH3 emissions.

(Garson, 2014). A simple fixed-effects model would treat data points as entirely independent. However, data is not independent but somewhat hierarchical, and random effects need to be incorporated besides the fixed effects. Hierarchical structures could appear when several observations are taken from the same observation unit over time or when those units of observations violate the independence assumption, as they are related to each other. In our case, PEV market shares are nested within the year but also nested within the department. Mixed-effects modelling is advantageous in our case since it gives us group-specific estimates of the parameters in the model, allowing us to understand precisely how the groups differ from one another. In addition, it takes into account the effect of variables, such as "Vehicle travelled mileage", that do not vary in time (a fixed-effect model would draw that out) but are essential to explain PEV sales. An alternative to mixed-effects models could be Generalized Linear models (GLM), which is also helpful for nested data. When using mixed-effects models, factors may have both a fixed and a random component, differing from Generalized Linear Models (GLM), where one must consider each factor as fixed or random. Still, parameter estimations in GLM can be problematic, which leads us to prefer the mixed-effects estimation (Garson, 2014).

We studied the logarithmic form of the new registered BEV and PHEV market shares for 94 departments in France, as the logarithmic form is highly recommended when the dependent variable is a percentage because it ensures the residuals' normality (Sprei, 2018; Wooldridge, 2012). Our analysis accounts for infrastructure availability because users will not buy vehicles they cannot recharge. However, charging infrastructure operators await a meaningful market share of vehicles so that charging stations become a profitable business.

The so-called "chicken-egg electric mobility problem", where each party awaits the other before acting. To avoid endogeneity problems from the simultaneity between PEV market shares and the installation of charging infrastructure, we studied the correlation between the lagged form of charging infrastructure departments densities of slow-and-normal speed combined, fast and fast ultra-fast speeds and BEV/PHEV market shares. In other words, we consider the effect of charging infrastructure densities, in chargers/km², for the year *'t-1'* on the market shares of the year '*t*' (i.e., 2014 to 2018). In addition, we consider the ratio of subsidies and the most sold vehicle in the department to capture the relative effect of subsidies over vehicle prices. Following the same logic, we compute the ratio of the bonus and the most sold vehicle in the department. Besides, we compute the ratio of electricity prices (in €/kWh) and gasoline prices (in €/l), following Münzel et al. (2019), since only the ratio will allow us to obtain the relative savings of energy costs of PEVs compared to ICEVs. We only include gasoline prices since including diesel prices would lead to potential collinearity among the two prices. Besides, we include the vehicle's electric range to account for anxiety in the purchase decision and the vehicle's travelled kilometre (VKT) daily trips (km). We transform the slow-and-normal chargers' density and the electricity over gasoline price ratio to the logarithmic form to linearize the model. To avoid the loss of observations with zero values, we transformed the fast and ultrafast chargers densities, and the ratio of subsidies and the most sold vehicle price using $\ln\left(x + \sqrt{1 + x^2}\right)$ (Busse, Königer, & Nunnenkamp, 2010).

We denote such transformations as $\widetilde{d}_{\text{fast chargers}}$ and $\widetilde{d}_{ultra-fast\ chargers}$ for the fast and ultrafast chargers' densities, respectively, $\widetilde{\frac{\text{subsidies}}{\text{price}}}$ for the ratio of local subsidies and vehicle price, and $\widetilde{\frac{\text{bonus}}{\text{price}}}$ for the ratio of national bonus over the most sold vehicle price. In addition, we added the difference in registration taxes, which are measured in Euros/BEV for every department. We include the number of available models for BEVs and PHEVs to capture the interrelation with PEV availability on purchase. Our model also investigates the impact of socio-demographic-economic factors: income (in thousands of Euros) for the year '*t*-1', the population density (people/km²), the proportion of the population belonging to the ages 20-39 and 40-59 (%), the unemployment rate (%), the proportion of households with two vehicles and at-home parking availability (%), the proportion of female (%), the proportion of people with a higher education degree (%), the level of emissions per capita (kg/capita), and solar production per capita (MWh/capita).

We used a mixed-effects regression to analyze the impact of charging infrastructure deployment and other socio-economic factors separately on both BEV and PHEV market shares, per department in France, from 2015 to 2019. Equation 3.1 describes the model:

$$
\begin{aligned}
\log\left(\mathbf{PEV_{i,t,z}}\right) = & \beta_{0_i} + \beta_1 \log\left(\mathbf{d_{slow,\ normal\ chargers_{it-1}}}\right) + \beta_2 \widetilde{\mathbf{d}}_{\text{fast chargers}\mathbf{i,t-1}} + \\
& \beta_3 \widetilde{\mathbf{d}}_{\mathbf{ultra-fast\ chargers i,t-1}} + \beta_5 \widetilde{\frac{\text{subsidies}}{\text{price}}}_{\mathbf{i,t,z}} + \beta_6 \text{diff}_{\text{taxes}\mathbf{i,t,z}} + \beta_7 \text{nb models}_{\mathbf{t,z}} + \beta_8 \widetilde{\frac{\text{bonus}}{\text{price}}}_{\mathbf{i,t,z}} + \\
& \beta_9 \log\left(\frac{\mathbf{p}_{\text{gasoline}_{\mathbf{i,t}}}}{\mathbf{p}_{\text{ectricity}_{\mathbf{t}}}}\right) + \beta_{10} \text{VKT}_{\mathbf{i,z}} + \beta_{11} \text{electric range}_{\mathbf{i,t,z}} + \beta_{12} \text{parking}_{\mathbf{at-home_i}} + \beta_{13} \text{two}_{\text{vehicles}_\mathbf{i}} + \\
& \beta_{14} \text{emissions}_\mathbf{i} + \beta_{15} \text{solar}_{\text{production}_{\mathbf{i,t}}} + \beta_{16} \text{income}_{\mathbf{i,t-1}} + \beta_{17} \text{unemployment}_{\mathbf{i,t}} + \beta_{18} \mathbf{d}_{\text{population}_{\mathbf{i,t}}} + \\
& \beta_{15} \text{education}_{\text{level}\mathbf{i}} + \beta_{16} \text{age}_{\mathbf{i,t}} + \beta_{17} \text{female}_{\mathbf{i,t}} + \varepsilon_{\mathbf{i,t,z}}
\end{aligned} \tag{3.1}
$$

Observations in our sample are Independent and Identically Distributed[14], the subscript *i* denotes the department (from 1 to 94), *t* denotes the year (from 2015 to 2019), and *z* denotes the vehicle type (BEV or PHEV).

For each variable, we determined the regression coefficients β. $\varepsilon_{i,t,z}$ is the random disturbance term.

3.4 Results

Looking at relationships between individual variables can help to highlight dynamics that are not evident in linear regression models. Table B.1 in Appendix B contains the correlation coefficients of all variables. The largest cross-correlation coefficient among a pair of independent variables is 0.93 (between the different charging infrastructure densities). We confirm the severity and magnitude of multicollinearity between the different charging infrastructure variables by considering the size of the Variance Inflation Factor (VIF). To correct multicollinearity, we used the logarithmic form of a variable that groups the densities of slow-and-normal charging infrastructure. The absence of severe collinearity is established, resulting in VIF values below 10 (Elliott, 2006). Regression results are presented separately for the BEV (Section 4.1) and PHEV models (Section 4.2).

[14]The errors are Independent and Identically Distributed if the meet the following two criteria: (1) Independence: The errors are independent, which implies that there is no correlation between consecutive residuals in time series data. (2) Homoscedasticity: The errors have constant variance conditional on the explanatory variables.

3.4.1 BEV model regression

We perform a mixed-effect regression[15], including social, demographic, technical, and economic factors to estimate their impact on BEV market shares. Table 3.2 displays the results of the BEV model. The model (model 1 in Table 3.2) presents a high goodness-of-fit (conditional $R^2 > 84.7\%$, marginal $R^2 > 43.8\%$[16]), representing a high explanatory power of our models.

Regarding economic factors, we obtain a relationship between subsidies relative to the price of the vehicle, registration tax exemption and higher BEV purchasing activity since they lower its upfront cost. A person receiving the most considerable amount of local subsidies, additional to the 5000€ national subsidies and paying zero registration fees, has a higher chance of purchasing a BEV. The national subsidies (Bonus) did not influence BEV sales since the value scarcely varies between years. As expected, lower taxes for BEVs is linked with switching to BEVs. On the other hand, the ratio of electricity price over the gasoline price is negatively correlated with BEV sales at a 1% level. Higher gasoline prices increase the trip cost of ICEVs and decrease the utility of this type of vehicle. They could potentially motivate consumers to switch to BEVs, leading to lower travelling costs and higher market shares. Parallelly, higher electricity prices relative to gasoline prices act as a disincentive to buy battery electric vehicles since it could motivate consumers to buy an ICEV compared to a BEV.

Additionally, the β coefficient on the number of BEV models available on the market is positive and statistically significant at a 1% level. Indeed, a 1% increase in the number of models in the market increases BEV's market share by 2 percentage points. Providing a variety of models on the market by the automotive industry will enhance the client's availability and, consequently, result in higher BEV sales.

Regarding the charging infrastructure deployment, we studied the impact of the lagged and logarithmic form of the public charging infrastructure densities on the $\log(BEV_{\text{ms}})$. Fast and ultra-fast chargers densities coefficients are statistically significant at a 1% and 5% level with

[15]We test for whether or not including a random effect structure is sustained, by comparing the AIC of the baseline model without random intercepts to the AIC of the model with random intercepts. A random effect structure is preferred since the AIC of the model with random intercepts is substantially lower than the AIC of the model without random intercepts (AIC random = 227.962 < AIC baseline = 428.3548).

[16]Conditional R^2 takes into account the variance of both fixed and random effects. Marginal R^2 corresponds to the variance of the fixed effects only (Barton, 2013).

β coefficients of 7.1 and 4.86, respectively. Therefore, an increase of 1 percentage point could increase BEV sales by 7.1 and 4.86 percentage points in the following period. On the contrary, the coefficient of the slow-and-normal chargers density is not statistically significant. Since slow, normal, and fast chargers are generally available in cities, regression results (Table 3.2) show that the main factor that concerns BEV adopters is fast public charging. Several hypotheses emerge from these results. We think charging tariffs and durations could play a vital role in driver preferences: BEV owners prefer to spend the shortest time charging the vehicle and paying more for charging services. This result is justified by a French survey (EVBox, 2020), where most respondents (46 % of BEV drivers) are ready to pay more for the less charging duration. Yet, it is impossible to include charging tariffs and durations in the regressions because they do not vary in time nor within the departments. Alternatively, results show that BEV adopters are convinced by ultrafast charging, available on highways to solve long-distance trips. This result is justified by (EVBox, 2020), where most respondents (55 % of BEV drivers) privilege the usage of ultra-fast chargers available on highways. However, further studies are needed to draw definitive conclusions about the influence on charging tariffs and durations.

Regarding the socio-demographic covariates, results showed an interconnection between the education level and higher BEV sales. This could be justified by increasing environmental awareness towards the benefits of BEVs, leading to higher adoption activity. Consumers with higher education levels might be more aware of the different vehicle choices' environmental effects and the relative performance of EVs compared to ICEV. Thus, they might be more willing to purchase electric vehicles. However, findings indicate a negative correlation between the proportions of the population having the minimum driving age (between 20 and 39, and between 40 and 59). We suspect that the concentration of this proportion of the population is higher in urban areas, which have public transport alternatives. Thus, these population categories could be more interested in the public transportation sector than individual means.

The results of the different models indicate no statistically significant effect for some covariates: socio-demographic (*the daily vehicle travelled kilometre (VKT), the at-home parking availability, local-solar production, the unemployment rate, the population density, emissions, the percentage of females in the population, and the proportion of households with a minimum* *of two vehicles*), economic (*income, national subsidies*), and technical factors (*the vehicle's electric range*).

3.4.2 PHEV model regression

We perform mixed-effect regression[17], including different social, demographic, technical, and economic factors, to estimate their impact on PHEV market shares using the logarithmic form. Table 3.2 displays the results of these models. Since different incentives are given to PHEV buyers, it should be noted that the difference in registration taxes is not included in the PHEV model, and the PHEV subsidies account for 50% of those offered to BEV adopters. Additionally, the number of available models covariate accounts for PHEV models only, and the price of the most sold vehicle is that of PHEV. The model (model 2 in Table 3.2) presents a high goodness-of-fit measure (conditional R^2>85.5%, marginal R^2>65.7%).

As for the economic factors, data show a negative correlation between the ratio of electricity price over the gasoline price and PHEV sales at a 1% significance level: an increase of 1 percentage point in electricity price compared to gasoline price could lead to a decrease of 4.5 percentage points in the PHEV sales. Therefore, travel cost savings are achieved using a PHEV, leading to higher sales. Also, an interesting finding is achieved: the ratio of national bonus over the vehicle's price is negatively correlated with PHEV sales. This is mainly due to the decrease of the national subsidies from 4000€ in 2015 to 0€ in 2018. Also, it represents a small part of a plug-in hybrid vehicle's price. On the other hand, local subsidies did not influence PHEV sales. Moreover, the income has a positive relationship to the PHEV demand at a 5% level

Similar to the BEV model, the β coefficient of the number of PHEV models available on the market is positive and statistically significant at a 1% level. A 1% increase in the number of models in the market increases PHEV's market share by 0.9 percentage points. Providing a variety of models on the market by the automotive industry will enhance the client's availability and, consequently, result in higher BEV sales.

The lagged form of slow-and-normal chargers densities coefficient is statistically significant

[17] We test for whether or not including a random effect structure is sustained, by comparing the AIC of the baseline model without random intercepts to the AIC of the model with random intercepts. A random effect structure is preferred since the AIC of the model with random intercepts is substantially lower than the AIC of the model without random intercepts (AIC random = 728.479 < AIC baseline = 854.594).

at a 1% level regarding the charging infrastructure deployment. An increase of 1 percentage point in the density of slow-an-normal chargers will increase PHEV sales by 0.064 percentage points in the following period.

Regarding the socio-demographic covariates, the availability of at-home parking is negatively correlated with PHEV sales at a 1% level. Although this variable could represent a proxy for private charger availability, we suspect it could also capture income effects since households with at-home parking are more common in departments with larger rural characteristics, which are also characterized by a lower household income. Indeed, the at-home parking and income correlation is high and significant at a 5% level, with a coefficient of -0.55 (Table 5 in Appendix B). Therefore, we believe that PHEVs are less likely to be bought, given that they are, on average, a more expensive choice.

In addition, an increase of 1% in the local solar production increases PHEV market share by 4.1 percentage points, meaning that a department with a higher solar energy production per capita, with a higher awareness level towards renewable energy, is related to the choice of PHEV purchase. This result also suggests that users are aware of the potential synergies that can be created between renewable energy production and PHEV ownership. Also, the unemployment rate has a negative connection to the PHEV demand at a 5% level.

Various covariates showed no significant effect on PHEV sales, namely socio-demographic (*the daily vehicle travelled kilometre (VKT), the education level, the percentage of females, the percentage of the population aged between 20 and 59, emissions, the proportion of households with a minimum of two vehicles, and the population density*), economic (*local subsidies*), and technical ones (*the vehicle's electric range*).

3.4.3 Comparison of BEV and PHEV models with the literature

Given that we differentiate between BEV and PHEV markets, while previous literature primarily focuses on PEVs combined, it is not straightforward to compare the results of our study with those of the literature. Nonetheless, we can still draw interesting insights from comparing the French case to other countries' results. Overall, the significant variables in our models that are correlated with higher BEV and PHEV sales are consistent with the literature (detailed in Table 3.1), such as financial incentives (national and local subsidies, difference in taxes), public charging infrastructure deployment, income, energy prices, education level, local-solar production and number of models. However, some factors, which existing literature found vital in higher PEV markets in other countries, do not have the same effect in France. For example, daily travelled kilometres, which is negatively correlated with BEV sales in Norway (Mersky et al., 2016), do not influence our models. In fact, the VKT in Norway is around 100 km round trip, compared to 30 km for France (ENTD, 2019; Mersky et al., 2016). Therefore, the electric autonomy of a 50 kWh BEV (300 km) is largely sufficient for French needs but could be risky for the needs of Norway, especially with the cold weather, which could explain the difference in our results. Besides, the population density and the percentage of females covariates positively influence PHEV and BEV sales in the U.S. (Clinton & Steinberg, 2019; Vergis & Chen, 2015; Wee et al., 2018), contrary to France, where no significant effect was found.

Concerning the public charging infrastructure deployment, several studies found this covariate to be a vital factor for purchasing a PEV in Norway (Mersky et al., 2016), European countries (X. Li et al., 2017; Plötz et al., 2016; Sierzchula et al., 2014), and the U.S. (Clinton & Steinberg, 2019; Vergis & Chen, 2015). Indeed, the influence of different charging speeds, which presents the novelty of this paper, was not considered in previous literature. We found that setting up fast chargers in cities and ultra-fast chargers on corridors could boost the BEV adoption trend. Contrary to the BEV market, where there is a negative effect, slow-and-normal chargers positively impact PHEV adoption. Since PHEVs cannot be charged using fast and ultra-fast chargers, these charging powers were not considered in our analysis of the plug-in hybrid market.

We differentiate between two types of subsidies regarding economic factors: local and national. Clients receiving local subsidies and registration fees exemption are more likely to buy a BEV in France, similar to China at the city-level (Wang et al., 2017), the U.S. at a state level (Vergis & Chen, 2015; Wee et al., 2018), and Europe (Münzel et al., 2019). However, local subsidies are not correlated to PHEV sales in France. In fact, the amount of local subsidies for PHEVs in France is minimal compared to the vehicle's price. Regarding the national subsidies, we do not obtain a significant correlation with BEV market share. We believe that these results are explained by the French national subsidy's low variability during our study's period (from 2015 to 2019). In the case of PHEVs, we find a negative correlation between national subsidies and PHEV market share. This is a particular result for the French case since PHEV subsidies decreased and reached 0€/PHEV in 2018. A previous study (Münzel et al., 2019) highlighted that national subsidies were essential in the BEV/PHEV purchasing activity in 30 countries. However, for the period of this study (between 2010 and 2016), governments of the 30 countries decided to increase the amount of the national subsidy. Interesting findings are drawn from the comparison of the economic covariates that could inspire policy recommendations. Local and national subsidies are an essential factor to incentivize PEV sales, but in a nascent market, their amount should also increase with time to convince drivers to switch to electric mobility.

We also found that the number of available PEV models positively correlates with market shares, while the ratio of electricity and gasoline prices negatively correlates with market shares. These results correspond to those of the previous literature, such as in (X. Li et al., 2017; Vergis & Chen, 2015; Wee et al., 2018). Our results also prove that the ratio of energy prices has a more vital negative interaction with PHEV sales than BEV sales: a one percentage point increase in the ratio leads to a decrease of 1.4 (*4.1*) percentage points in BEV (*PHEV*) sales. This result is expected since a PHEV is highly dependent on fossil fuels. Contrary to BEV users, PHEV users have to constantly trade-off between using electricity or gasoline to fuel their vehicles. Non-financial incentives, which proved to correlate with PHEV and BEV markets in Europe and the U.S. (Plötz et al., 2016; Soltani-Sobh et al., 2017), were not included due to the lack of data. This covariate is noteworthy for further studies to develop France's BEV and PHEV markets.

Regarding the socio-demographic variables, we find differences between our study and previous literature, when disentangling the effect for the two vehicle types (BEV and PHEV). For instance, higher education level correlates with higher sales for only the BEV market, similar to the studies conducted in Europe (X. Li et al., 2017) and the U.S. (Clinton & Steinberg, 2019). Local solar production is positively associated with only higher PHEV purchasing activity, such as in the study conducted in Europe (X. Li et al., 2017). The unemployment rate and at-home parking availability only negatively affect PHEV sales. Yet, the unemployment rate did not influence BEV sales in Norway (Mersky et al., 2016). Overall, our results align with the existing literature on early PEV adopters across the countries. However, it is essential to consider other covariates in further studies, such as non-financial incentives and actual private charging infrastructure deployment data.

As a contribution to the literature, we examined the relationship between some variables, local emissions, the vehicle's electric range, and the proportion of households with a minimum of two vehicles, which were not considered in our selection of papers. These covariates did not have a significant effect on BEV and PHEV markets. Moreover, we contribute to the literature by considering the effect of the different charging speeds in PEV adoption, analysing a department-level French case study and considering the relative effect of financial incentives with respect to the price.

Table 3.2: Regression results of logarithmic form of BEV and PHEV market shares

	Dependent variable:	
	Log BEV Market Share (1)	Log PHEV Market Share (2)
Log Slow and Normal Chargers Density	-0.029*	0.064***
	(0.017)	(0.020)
Log Fast Chargers Density	7.100***	
	(2.550)	
Log Ultra-Fast Chargers Density	4.865**	
	(2.008)	
Log Local Subsidies/Vehicle price	1.047***	-1.295
	(0.401)	(1.395)
Log National Bonus/Vehicle price	1.698	-0.930**
	(1.720)	(0.439)
Difference in Registration Tax	0.003***	
	(0.001)	
Number of Models	0.020***	0.009***
	(0.005)	(0.002)
Log Electricity price/SP95 price	-1.457***	-4.177***
	(0.336)	(0.463)
VKT	0.003	0.018
	(0.011)	(0.013)
Vehicle's electric range	-0.002	-0.001
	(0.002)	(0.002)
Parking at home	-0.159	-0.321***
	(0.100)	(0.119)
Two Vehicles	0.014	-0.011
	(0.010)	(0.012)
Emissions	0.002	-0.002
	(0.001)	(0.001)
Solar Production	-0.131	0.413***
	(0.108)	(0.135)
Income	0.00001	0.00005**
	(0.00002)	(0.00002)
Unemployment	0.011	-0.059**
	(0.020)	(0.024)
Population density	0.00001	-0.00004
	(0.00002)	(0.00002)
Education	7.337***	-2.245
	(2.070)	(2.470)
p20-39	-6.131***	-0.156
	(2.015)	(2.465)
p40-59	-13.015***	-7.323
	(3.887)	(5.033)
Female	-0.022	0.090
	(0.075)	(0.092)
Constant	-4.127	-16.834***
	(4.634)	(5.817)
Observations	470	469
Conditional R2	0.848	0.855
Marginal R2	0.438	0.657
Note:		*p**p***p<0.01

3.5 Robustness checks

We applied different robustness checks, such as omitting nineteen random regions, excluding big cities, removing charging infrastructure covariates to identify their impact on our models.

3.5.1 Robustness check 1: Removing random departments

We examined the impact of omitting random 19 departments on the model; results are shown in Table B.2 in Appendix C (models 2 and 4). It should be noted that the coefficients of the regression are an estimation of all the studied regions and are equally calculated for all the departments. We conclude that the model is robust since the estimation results of both BEVs and PHEVs market shares do not significantly change in any coefficients or significance.

3.5.2 Robustness check 2: Excluding departments with big cities

We omit departments where Paris, Marseille, and Lyon[18] are located[19]. Results are shown in Table B.3 in Appendix C (models 2 and 4). We obtain that fast chargers density have no impact on BEV market share, mainly due to the different types of usage of BEV in small and big cities. In small cities, contrary to big ones, more private parking is available at households (INSEE, 2016), leading to a higher probability of at-home chargers installation; and, thus, lower usage for public fast chargers. Also, the ultra-fast charging density remains significant because it is mainly used for long-distance trips and these chargers are available on highways.

3.5.3 Robustness check 3: Removing charging infrastructure control variables

As a third robustness check, we exclude charging infrastructure variables. The results, which are shown in Table B.4 in Appendix C (models 2 and 4), showed slight variations in the coefficients and significance of the control variables of the BEV/PHEV regression models. For instance, the ratio of subsidies and price, and the ratio of electricity and gasoline price increase in absolute value, compared to the case with charging infrastructure. Not considering charging

[18]We eliminated Paris, Lyon and Marseille as they are the most populated cities in France, and they have the largest metropolitan areas (INSEE, 2020a).

[19]The departments removed are Paris (75), Bouches du Rhône (13), and Rhône (69).

infrastructure leads to an overestimation of both the subsidies and the energy prices ratios in the BEV model.

Only a maximum of 1% of the variation in the conditional goodness-of-fit was measured for all the models. While the charging infrastructure variables are essential predictors of BEV and PHEV sales, these variables are not the largest predictors of vehicle sales. However, including charging infrastructure variables is essential since they slightly improve the goodness-of-fit and reduce the predicted value's bias in other model independent variables.

3.6 Policy Recommendations and Conclusions

3.6.1 Policy Recommendations

Based on our results and to accelerate the electric mobility transition in France, this paper provides policy recommendations for the members of the PEV ecosystem: the automotive industry, the charging operator, and government/local authorities.

First, our results found that the number of available models on the market is positively correlated to both BEV and PHEV sales. Therefore, we recommend automotive manufacturers adopt a strategy to promote PEVs by providing various models of different sizes, battery capacities/ranges, styles, and designs. This recommendation implies incurring in R&D and manufacturing costs but can potentially increase brand visibility and help differentiate from competitors. Also, installing more solar panels proved to be correlated with higher PHEV sales. Therefore, we urge the French local authorities to provide facilities for PV panels' instalment since it could increase the environmental awareness towards green technologies.

Second, results show that deploying fast and ultrafast chargers positively correlates with the BEV market share, contrary to slow-and-normal chargers. Also, slow-and-normal chargers positively relate to the PHEV market share. Although we cannot confirm the rationale behind these results, we suspect that having more infrastructure in the market, decreases range anxiety for PEV users and increases awareness of these technologies. The decision of charging speed instalment should be aligned with the French and European directives: targeting BEV or PHEV technologies. Therefore, charging infrastructure operators should consider a strategic plan that includes providing public fast chargers to target potential BEV users, public slow-and-normal chargers to target potential PHEV users and ultra-fast chargers on highways rather than other charging speeds. However, we should consider that installing the different charging stations entails various costs and benefits. Regarding costs, fast and ultra-fast chargers come with higher investments than slow-and-normal chargers (Table 3.2) and additional costs, such as grid reinforcement and connection. Regarding benefits, charging operators should consider the charging behaviours of PEV users in order to evaluate their revenues and fix their charging tariffs. Besides, we recommend local authorities concentrate their efforts on providing and/or increasing subsidies to the instalment of fast chargers where BEVs are ascending, slow-and-normal chargers where PHEVs are ascending, and ultrafast public chargers on highways.

As discussed before, economic factors present promising opportunities for new policies to achieve low-emissions goals. Results show that local subsidies and registration tax exemption are two crucial reasons for mass BEV adoption. Indeed, the higher the ratio subsidy over vehicle price, the higher the chance is to buy a BEV. Therefore, we suggest local authorities offer subsidies based on the vehicle's price: more subsidies should be offered for higher BEV prices. Also, we recommend that the French government revise the national BEV Bonus because it does not influence its sales. Regarding PHEVs, the relationship between the ratio of national bonus over the vehicle's investment presented a negative correlation with PHEV sales. Also, we concluded that there is no influence of local PHEV subsidies on its sales. Therefore, we recommend that the French government reconsider the amount of these incentives after eliminating them in 2018 and local authorities revise their incentives. The case of PHEV remains open for further studies. By modifying these financial incentives and economic factors, local authorities and governments should expand their PEV markets and potentially help to achieve their road electrification targets. Indeed, the choice to offer incentives to BEV or PHEV purchasing activity should be based on the governmental roadmap: to fully or partially decarbonize the road transportation sector.

Moreover, gasoline prices have a significant and positive impact on BEV and PHEV markets. Since travel cost savings could be achieved by purchasing a PEV, governments should consider gasoline taxes as tools to encourage clients to buy PEVs. Indeed, the French government adopted their strategy to add taxes on fossil fuel prices, namely the carbon tax, the fourth governmental source of income (Senat, 2018). The government has been increasing the diesel price more than gasoline price due to its environmental impact, pushing ICEV owners to switch to low-emission vehicles (Pennec, 2017). Under the two laws: Energy Transition Law for Green Growth[20] and The National Low-Carbon Strategy[21], this strategy provides price signals encouraging low-carbon mobility to drivers (French Ministry of Ecological Transition, 2020c; Pennec, 2017).

However, increasing the carbon tax led to social movements, namely the "Yellow Vests", pushing the French government to suspend additional taxes on fossil-fuels prices. Indeed, increasing taxes has no social acceptability in France[22] since the country is one of the top-taxed countries in the European Union (OECD, 2021). Overall, the French government should create a roadmap that accompanies the electric mobility transition: by (1) revising national and/or local subsidies for BEVs and PHEVs, (2) decreasing the electricity price and/or increase gasoline price, (3) offering subsidies for charging operators to install the right charging power at the right place. Despite the influence of these recommendations on achieving climate targets, governments should consider social and budgetary costs in implementing them. For instance, increasing subsidies for both consumers and charging operators entail increasing taxes, and governments should first determine the less costly option. Besides, increasing gasoline taxes, which presents a source of revenue for the government (Senat, 2018), could provoke social movements. As for decreasing electricity prices, the French government should evaluate its feasibility since prices are managed at the European level. Indeed, a Cost-Benefit Analysis, which is not the goal of this paper, is needed to prioritize policies according to their social, environmental and economic impacts.

3.6.2 Conclusions

This paper uses mixed-effects regression to explore the impact of 21 socio-techno-economic factors across the PEV adoption activity in 94 French departments between 2015 and 2019. We identified candidate factors that could potentially impact BEV or PHEV sales based on a

[20]Loi de la Transition Energétique pour la Croissance Verte (LTCEV)

[21]Stratégie Nationale Bas-Carbone (SNBC)

[22](“Les Français refusent de payer à nouveau la taxe carbone,” 2019; “Relance économique,” 2021)

literature review before gathering their datasets from various sources. Then, we chose to apply mixed-effects models to investigate BEV and PHEV purchasing activity evolution, separately. The purpose of developing these two models is to: (1) study the influence of different-power charging infrastructure deployment, French department-level subsidies concerning the vehicle's price, and the vehicle's electric range on PEV adoption, and (2) conclude with policy recommendations to draw a roadmap for electric mobility transition in France.

Our BEV and PHEV models present goodness-of-fit measures (conditional R^2>84.7% for the BEV model and conditional R^2>85.5% for the PHEV model). The results show that the number of available PEV models, and energy prices positively influence both BEV and PHEV market shares. Results indicate that the covariates with a positive effect on BEV sales include economic variables (income, taxes exemption, the ratio of subsidies over the vehicle's price), technical variables (fast and ultra-fast charging density), education level, and the number of available BEV models. Yet, higher electricity price regarding gasoline price negatively relates to BEV sales, similarly to the proportions of ages between 19-39 and 40-59. Besides, the positively correlated variables with PHEV sales include the number of PHEV models, income, slow-and-normal chargers density, solar production, and daily travelled kilometres. However, the bonus (the national-level subsidy) accounting for a small part of the PHEV investment value, the unemployment rate, at-home parking availability, and electricity price significantly but negatively affect PHEV sales.

This paper ends with policy recommendations to the main stakeholders contributing to the development of electric mobility. First, these directives are highly dependent on the French or European directives: fully or partially decarbonizing the road transportation sector. Here, we concluded with general conclusions of correlation between covariates and both BEV and PHEV sales. Firstly, we suggest automakers to increase the variety of PEV choices. Moreover, we recommend charging operators to provide fast chargers in BEV-ascending cities, slow-and-normal chargers in PHEV-ascending cities, and ultra-fast chargers on highways.

Lastly, we propose a roadmap for the French government to follow the electric mobility transition by: (1) for BEVs: increasing local subsidies and revising national bonus, (2) for PHEVs: revising both national and local subsidies, (3) decreasing the electricity price or increasing gasoline price, (4) offering subsidies for charging operators to install the right charging power at the right place, and (5) providing facilities to the instalment of PV panels. However, governments must be aware of the adverse consequences of policies. To limit the consequences of social movements, like the "Yellow Vests" in France, governments should consider adopting the three policy recommendations simultaneously. That is, coupling the increase of gasoline prices with the provision of financial incentives for BEVs and PHEVs (i.e. subsidies, tax exemptions), the provision of subsidies for the instalment of charging infrastructure, and the decrease of electricity and charging tariffs.

While some of the findings of this study were expected and despite the high resolution of our analysis, further studies are suggested to boost these models by considering other socio-techno-economic factors that were not considered due to the lack of data, namely at-home and at-work charging infrastructures of both the department of residence and work, the tariffs of public charging infrastructure, local non-financial incentives, and electric mobility services (Vehicle-to-Grid, smart charging, and carsharing). Our model can only draw general conclusions since the PEV market share in France represents less than 5%, so-called Early Adopters stage. It would be helpful to perform a follow-up study in a more developed market. Additionally, the model does not capture the customer's psychological effect, which could be affected by the marketing campaign of both automotive manufacturers and charging infrastructure operators. The paper aims to draw a clear roadmap for electric mobility transition by identifying the market-booster factors rather than concluding with definitive causation. Therefore, to know if these policies are efficient in a societal and economic sense, we recommend that future studies consider a cost-benefit analysis.

CHAPTER 4

INTEGRATED STRATEGIES IN AN ECOSYSTEM CONTEXT: EVIDENCE FROM THE EU PUBLIC CONSULTATION ON CONNECTED AND AUTOMATED MOBILITY

Maria Teresa Aguilar Rojas[1 2]

Abstract

Innovations bring cooperation and competition challenges in both the market and non-market environment. In the market environment, firms with diverging interests, are more tightly interdependent and their success depends on other firms pertaining others in their ecosystem. In the non-market environment, firms lobby to shape regulations that favour their interests. We are interested in understanding the behaviour of firms when facing competition and cooperation issues in both market and non-market environments. Particularly, we analyse the factors that influence firms' alignment in the non-market environment. We take the specific case of the EU public consultation on connected and automated mobility, where firms could inform their preferences regarding two topics: cybersecurity and data protection. We perform a network analysis on the consultation responses and a logistic regression analysis to determine the likelihood of firms to align in the non-market environment when they had formed market alliances and ecosystems. Results show that, for both topics, firms tend to align their responses to the consultation with ecosystem partners. Similarly, firms tend to align their non-market strategies with other firms from the same sector. Differences in alignment can also be found between topics. For cybersecurity, a technically-oriented topic, larger companies tend to align their non-market strategies, while for data protection, a more institutionally oriented topic, firms tend to align with other firms from the same country.

Keywords: Integrated Strategies, Non-market Strategies, Ecosystems, Coopetition

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[1] University Paris-Dauphine (PSL), Governance and Regulation Chair, M&O Laboratory

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4.1 Introduction

Along with new opportunities, innovation ecosystems bring new challenges as firms are more tightly interdependent with each other. Innovation ecosystems are organized around a focal value proposition, where firms use their specialization to develop one or multiple components that form the focal offer (Adner, 2017; Jacobides, 2018). This is especially the case for highly innovative offers, for which the technological complexity and required resources are considerable. Hence, a single firm no longer can independently control the production process of the focal offer. The interdependence feature becomes a challenge as the success of a firm depends on the collaboration with other firms in the ecosystem. However, cooperation among firms in an ecosystem context does not exclude the inherent nature of firms to compete with each other to capture value within the ecosystem. Cooperation and competition, —or *coopetition* (Brandenburger & Nalebuff, 1996) is innate of innovation ecosystems. Competing firms collaborate to facilitate and speed up the focal offer, provoking that a firm's success depends strongly on other competing firms belonging to the ecosystem. This is the case in the autonomous vehicle (AV) ecosystem. Firms from multiple industries (e.g. software, hardware, automotive) collaborate to develop or improve components of the autonomous car (such as different sensor technologies, cameras, software and HD maps, which are highly complex to develop) and compete to capture most of the rents inside the ecosystem.

Aside from the complexity in the technological and organizational aspects of innovation ecosystems, there are regulatory barriers. Oftentimes, highly innovative solutions have the potential to reshape sectors, industries, and consumers' habits, among others. Yet, regulations in place are not prepared to enable and foster these innovations due to lack of information or acceptability, which may impede the development and scaling-up of the focal offer. This is true for autonomous vehicles. For instance, vehicle safety regulations in terms of the speed of the vehicle are necessary for software manufacturers to program their cars to act within the bounds selected. Regulations will also determine the guidelines to ensure the cybersecurity of the vehicle, data protection and access. Systems can face unintentional, or worse, intentional threats that interfere with the system and put the vehicle, its passengers and surroundings in threat. Besides, the higher connectivity also allows service providers and automakers to collect more tailored data from users. Some of the collected data correspond to passenger personal information, location, habits, and sensor data on surroundings. Hence, another risk corresponds to the usage and ownership of the data. For the optimal deployment of AVs, regulators have the task to ensure the proper function of autonomous vehicles, while reassuring users about the safety of the vehicles and the privacy of their data, and proposed a consultation that allows the key actors to express their views on both topics. Likewise, enabling tests in cities, which are fundamental for training the algorithms of the AV, require approval from institutional actors. Some of the most relevant and pressing issues for regulators are: (1) enabling coordination to ensure vehicle safety and interoperability across borders, (2) prioritise safety, (3) remaining technology-neutral, (4) establishing rules that ensure data protection and ethics, (5) determining the usage and storage of data to improve potential liability issues, and (6) ensuring social inclusion.

The regulatory stakes are high since rules will shape how AVs will be implemented and deployed. For example, regulators could opt to implement a mandated standard for vehicles' safety or allow for voluntary standards. Mandatory regulations can better ensure the interests of consumers, as they can be more stringent in terms of safety guidelines and focus on ensuring interoperability as compared to private standards. As an illustration, J. Anderson et al. (2016) provide an overview of some of the private standards applicable to AVs and the potential shortcomings. For example, the ISO standard for lane departure warning states "An easily perceivable haptic and/or audible warning shall be provided" (J. Anderson et al., 2016; ISO, 2007). Yet, there is no clear definition of what "easily perceivable" mean, nor who the target driver is. The authors also point out that no private standard has concentrated on defining conformance requirements (i.e. test methods and procedures), which are crucial to determine the compliance of technologies with the specifications (J. Anderson et al., 2016). A similar situation occurs with cybersecurity standards. Voluntary standards may be too flexible with the treatment of data, which can discourage potential users to adopt the technologies and some of the private actors to share their data given the risk of cyberattacks.

However, mandatory standards also have their shortcomings. For instance, they may be too severe to implement, causing the market deployment of AVs to lag. Several AV manufacturers, for example, are already developing vehicles with new characteristics. Zoox, a purpose-built AV maker, claims to have designed a completely new type of airbag for their vehicle, as well as a system that uses sensors, switches, and cameras to ensure proper seat belt usage among passengers (Bellan, 2022). Many of these innovations do not necessarily evolve in the expected direction, which can make regulations and standards obsolete, or hinder the technology's development. The opportunity for value capture is also higher for certain actors, notably automakers, that develop voluntary standards.

Regulations could also favour and disfavour some stakeholders with their decisions. One example is through the definition rules that determine ownership and management of data. For instance, regulators can set standards that oblige companies that hold vehicle data (i.e. car manufacturers) to anonymise it and to share it with other stakeholders. This represent high costs for the data holders, and open the gate to other companies to capture value from their asset data (i.e. insurance companies).

On that account, firms are interested in interacting with institutional actors (i.e. regulators, policymakers) in the non-market environment to provide information, attempt to overcome the barriers linked to regulation and exert influence on their policy preferences. And, to have more leverage towards the regulator, they are interested in cooperating in the non-market environment with those that belong to the same ecosystem, who, a priori, have the same interest in seeing the ecosystem thrive. However, as seen in the previous examples, firms are not driven by the exact same incentives in all the topics when communicating with institutional actors. Thus, they also have reason to compete in the non-market environment.

When cooperation and competition forces interact in the market and non-market environments, firms can either adopt an integrated strategy, by coupling the cooperation efforts of pertaining to an ecosystem (market strategy) and of aligning in their lobbying practices (non-market strategy), or by dissociating market and non-market strategies. In the former, non-market strategies are shaped by taking into account not only a firm's interests but also the interests of its partners. Yet, little is known about the coopetitive tensions among firms in political markets, and even less when considering the integration of non-market strategies with market strategies.

In this study, we analyse the behaviour of firms pertaining to an innovation ecosystem, especially when it comes to adopting an integrated strategy or opting out of it. We concentrate on the specific case of the EU public consultation on connected and automated mobility, where firms could inform their preferences regarding topics like cybersecurity and data protection. We select the AV ecosystem as it reunites the coopetitive tensions in the market and non-market arenas and is characterised by a high uncertainty in the regulatory framework. Results indicate firms tend to align their responses to the EU consultation with firms with whom they have partnered to develop the autonomous car. In addition, firms are more likely to cooperate in the market arena with other firms from the same sector. We also observe differences between the two topics. organisations based in the same country tend to align in the lobbying for data protection and governance issues, but not in cybersecurity. However, having the same size does influence alignment when lobbying for cybersecurity, compared to no effect on data protection and governance issues. We contribute to the research on both ecosystems and integrated strategies. We enrich the literature on ecosystems by analysing the non-market component in this context. Besides, we expand the empirical research on integrated strategies by adding the ecosystem dynamics factor.

The rest of this paper is organised as follows. Section 4.2 presents the context of the study. In Section 4.3, we describe the literature review. Section 4.4 details the Theoretical framework. Section 4.5 specifies the data and the empirical strategy, followed by regression results in 4.6. Conclusions are provided in Section 4.7.

4.2 Context

4.2.1 The autonomous vehicle ecosystem

Broadly, autonomous vehicles can be defined as vehicles able to operate by themselves with zero or no human intervention. Nevertheless, there are different categorizations of what an autonomous vehicle is, depending on the level of autonomy. The EU Regulation 2019/2144 regarding motor vehicles divides autonomous driving into two terms: An 'automated vehicle' corresponds to "a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required". A 'fully automated vehicle' means "a motor vehicle that has been designed and constructed to move autonomously without any driver supervision" (European Parliament, 2019). Besides, the Society of Automotive Engineers (SAE) provides a classification of vehicle automation consisting of 6 levels (SAE, 2021). At level 0 (momentary driver assistance), human drivers stay fully engaged and attentive, while the vehicle provides temporary driving assistance, such as warnings and alerts, or emergency safety interventions. At level 1 (driver assistance), human drivers carry out most of the functions, while the vehicle provides either steering or brake/acceleration. At level 2 (additional assistance), human drivers carry out most of the functions and the vehicle assists on both steering and brake/acceleration. At level 3 (conditional automation), the vehicle's system drives under certain conditions, but the human driver should be prepared to take control when necessary. At level 4 (high automation), the vehicle system drives and does not need human intervention, under a defined condition. At level 5 (full-automation), vehicles can drive under all conditions with no need for human intervention.

The construction of autonomous vehicles has a certain level of complexity, which restrain actors to innovate by themselves. Hence, in line with the resource-based view, firms forge inter-organisational ties to obtain access to resources outside their boundaries to gain a competitive advantage. Particularly when facing rapid-changing technologies it is hard for firms to be able to build new competencies without using external resources via inter-organisational ties (Wadhwa et al., 2016), which is the case for AVs. Indeed, to build an AV, firms organize around an "innovation ecosystem". That is, the ecosystem reunites different types of actors from multiple sectors, like car manufacturers (e.g. Renault and Toyota), software developers (e.g. Microsoft), hardware providers (e.g. Bosch), service providers (e.g. Uber), among others, who draw on their capabilities to produce one or multiple components necessary for the development of the autonomous vehicle. Examples of ecosystem dynamics can be found in recent years. For example, General Motors, Volkswagen, and Mobileye (a company specialising in vision-based, driver-assistance systems) partnered to launch a crowd-sourced mapping technology for AVs. Similarly, Toyota and Microsoft have a long-standing partnership to improve vehicle telematics. In the first case, we observe that companies with an originally competitive relationship are working together in R&D for AV development, while in the second, companies that are new to the automobile industry, enter the market and couple their efforts with incumbents in the automobile industry.

4.2.2 The EU Public Consultation on Connected and Automated Mobility

Autonomous vehicles have raised the interest of the general public, and policymakers since they can bring several advantages. First of all, they are an opportunity to shape consumer preferences for transportation to a service-based offer, reducing the need for a privately-owned car. The possibilities are vast. For instance, several startups, like TuSimple, are building autonomous trucks for the long-haul transport of merchandise. Uber and Lyft are in the test phase of AVs to complement (or eventually substitute) the services provided by current Uber drivers. Waymo and Cruise, the subsidiaries in charge of AV development for Alphabet and General Motors respectively, are each planning their own car-sharing services with autonomous cars. The reduction of privately-owned cars has implications for the urban planning of a city and for land usage. Additionally, AVs can provide in-vehicle infotainment, since users are no longer implied in the driving process. We can imagine a wide range of services inside the car, depending on consumer patterns and their time usage inside the car (e.g. sleeping, working, playing video games, among others). Companies like Netflix are already offering their streaming platform in Tesla's vehicles.

There is also an opportunity to couple AVs with public transport, and reduce the inefficiencies related to the first and last-mile transportation. Navia supplies transport operating companies of autonomous shuttles that are intended to be combined in the public transport system. Companies in the retail industry, like Walmart and Amazon, are testing AVs for door-to-door delivery. Furthermore, autonomous vehicles can potentially reduce car crashes, congestion, greenhouse gas emissions and air pollutants, while increasing accessibility to vulnerable populations (e.g. deserving handicapped and elderly populations).

However, AVs face a number of risks and potential disadvantages that could hinder their acceptance by the general public (Taeihagh & Lim, 2019). One of them is data protection and governance. Autonomous vehicles rely on enormous amounts of data collected from sensors, HD maps, and other sources, to ensure the well-functioning and technological safety of the vehicle (West, 2016; Dhar, 2016). However, the ownership, control and usage of the data collected is a concern for the users and still remains unclear (J. Anderson et al., 2016) (Boeglin, 2015), and could bring different issues like lack of transparency with the data collected, excessive collection and retention of the data, and security. This can discourage users to switch to AVs and potentially impede the market to thrive. Thus, the decision on what data should be shared and in what format is crucial for regulators. Currently, the General Data Protection Regulation (EU) 2016/679 (GDPR), which establishes the guidelines on data protection and privacy in the EU, not only considers information such as the driver's name, address and contact details, but also location as private data. In the legislation, the principles of "privacy by design" and "data minimisation"[3] are pushed forward (European Parliament, 2016).

Up to now, there is no clarity on who owns the data. Car manufacturers could gatekeep the data they produce and claim that they are the rightful owners since their IT infrastructure (inside or outside the vehicle) allows for its collection. In a report drafted by the ACEA, whose members are some of the major car manufacturers (i.e. Ford, PSA, Renault, Toyota Volkswagen, Volvo, among others), the possibility of charging for the data created by car manufacturers is evoked. Nevertheless, access to data is highly valuable to multiple stakeholders in the market. For example, car manufacturers will have first-pass access to vehicle status and performance, such as vehicle speed, and battery life. Besides, when offering on-demand services, service providers could access unlimited types of personal data such as the address, bank account, billing information, and driving habits of users, among others. These data could be used to improve the safety and performance of their vehicles and the attached services. Insurance companies would be interested in obtaining driving habits data, to suggest more tailored insurance contracts by having knowledge, which car manufacturers can easily have. Retailers and service providers would profit from attracting users to their locations (J. Anderson et al., 2016). All in all, companies who own the data can have an enormous advantage since they can manage to achieve greater efficiencies in their service or product, and exploit possibilities for new services.

Another topic of concern is cybersecurity. AVs will require consumers to reveal a vast amount of personal data such as the address, bank account, billing information, driving habits,

[3]Data minimisation is a principle that states that personal data shall be "adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed".

and location of users, among others. Data theft becomes then a major concern for regulators, who are aware of the risk of cyber-attacks. For instance, the hackers Miller and Valasek demonstrated that malicious attacks on AVs are a near-term possibility in 2013, as they hacked a Chrysler Jeep through its internet connection and took control of its engines and brakes (Greenberg, 2015; Schellekens, 2016). A survey across 109 countries showed that software hacking and misuse of vehicles with all levels of automation were the highest concerns for users (Kyriakidis, Happee, & de Winter, 2014). Possible cybersecurity threats can include tricking global navigation satellite systems (GNSS) (Bagloee, Tavana, Asadi, & Oliver, 2016), altering sensors by increasing brightness to blind cameras, or interfering with radar to blind them from incoming objects (West, 2016), or hack communication channels (Dominic, Chhawri, Eustice, Ma, & Weimerskirch, 2016). Controlling cybersecurity risks is of major concern and guidelines and certifications of security procedures for the vehicle are topics on the agenda for the EU and other stakeholders. If unresolved, a market failure could occur since risks could scare purchasers, delaying or hindering the widespread adoption of AVs, therefore, leaving behind the positive externalities that characterize the technology.

The automotive industry is of major importance to the European economy, corresponding to over 7% of its GDP. The EU is one of the biggest producers of motor cars in the world and receives the largest share of private investment in R&D. In addition, it creates around 13.8 million direct and indirect jobs, representing a 6.1% of total EU employment. Besides, it is highly linked to the well-functioning of other upstream and downstream industries such as steel, chemicals, ICT and mobility services (European Commission, 2022). Accordingly, the EU has a high interest to stay up-to-date with the technology and integrate it, while avoiding the potential risks of its implementation. Indeed, the EU has the ambition to be a world leader in the deployment of automated mobility. With autonomous vehicle technologies, Europe aims to reduce road accidents and congestion, improve the public transport system and create synergies between autonomous and electric vehicle technologies, to foster the decarbonisation of the industry.

To achieve that aim, the European Commission has been working on the EU policy agenda for safe, clean and automated mobility, and has employed tools like public consultations to determine the main challenges for autonomous vehicle deployment. Public consultations are regulatory tools used to communicate with stakeholders, that is, individuals and organisations who are directly or indirectly affected by a proposal or decision, who can influence the decision, or who have a particular interest in the project, and seek their views on new initiatives, or existing policies and laws.

The public consultation on connected and automated mobility (CAM) had the aim to receive input from stakeholders on the challenges of the transition to autonomous mobility, such as cybersecurity and trust issues, data governance and privacy, and the use of 5G commercial bands (European Commission, 2019). The consultation was launched from October to December 2018, by the Directorate-General for Communications Networks, Content and Technology (DG CNECT). It was open to the relevant stakeholders, public or private (e.g. car manufacturers, service providers, telecom providers, end-users among others), as well as to the general public. There were two sets of questions: a first set addressed to the general public and a second set addressed to the relevant stakeholders. The consultation receive a total of 630 responses, divided into 469 from citizens and end-users, 137 from business businesses and association businesses and 24 from public authorities.

4.3 Literature Review

Three streams of research are useful for this study: ecosystems, non-market strategies, and integrated strategies literature.

Ecosystems

The term ecosystem broadly refers to a group of firms that interact with each other and depend on each other activities (Adner, 2017). While there is no convergence on the definition of ecosystems in the strategic management literature, we can identify different perspectives to understand the concept: The "business ecosystem" organizes around an "orchestrator firm" that coordinates other participant firms (e.g. Airbus (Adner, 2017)). The "platform ecosystem" organizes firms connecting via a central platform through a shared technology or technical standard and benefiting from the access to platform customers (e.g. video game developers (Jacobides et al., 2018)). The "innovation ecosystems" organizes firms around a common value proposition (e.g. PCs Ethiraj (2007), solar photovoltaic panels Hannah and Eisenhardt (2018)). Adopting the latter perspective, we define ecosystems as complex networks of firms evolving from the unbundling of formerly vertically integrated industries and from the convergence of previously distinct sectors, with the objective to develop a common value proposition (Adner, 2017; Iansiti & Levien, 2004; Jacobides, 2018).

The networks forming an ecosystem emerge from inter-organisational ties to develop "common value propositions". In line with the resource-based view, firms forge inter-organisational ties in order to obtain access to resources outside their boundaries to gain a competitive advantage. Particularly when facing rapid-changing technologies, it is hard for firms to be able to build new competencies without using external resources via inter-organisational ties (Wadhwa et al., 2016). The most frequent type of tie consists of non-equity alliances (Rothaermel & Boeker, 2008) - agreements between two or more parties forged to facilitate the pursuit of a common strategic goal and the sharing of created value. Some other types of ties, such as equity alliances are used to create value.

The multiplicity of actors in an ecosystem creates new competition and cooperation dynamics in the strategic field. Competition exists at two levels. The first type of competition is between stakeholders in the same ecosystem. organisations compete on positions, roles, and the distribution of value between them. The second type is across ecosystems since they compete for creating and capturing value (Adner, 2017).

Here, we draw from the literature a trade-off between cooperation and competition in an ecosystem. Firms must collaborate and depend on each other to create (Ethiraj, 2007; Hannah & Eisenhardt, 2018) and impose their value proposition with respect to other ecosystems (Adner, 2006, 2017). On the other hand, firms must compete to capture value (Hannah & Eisenhardt, 2018; Jacobides et al., 2016).

Non-market strategies

A firm's performance is not only shaped by the market environment. The institutional environment, consisting of the social, political, and legal spheres that are relevant to firms' activities (Baron, 1995), also has the potential to shape firms' performance. In this context, firms are interested in influencing the institutional environment to their advantage, and they do so, by employing non-market strategies (Baron, 1999). A study conducted by Bonardi, Hillman, and Keim (2005) conceptualizes the interaction between interest groups and political actors by viewing the political environment as a market for public policies. The demand side consists of organisations seeking public policies, while the supply side consists of politicians issuing legislation. Thus, non-market strategies are the tools used by the demand side to influence the supply side of the political market. Some examples of non-market strategies are electoral campaign contributions, lobbying and CSR.

One of the most commonly used non-market strategy is lobbying. Lobbying is generally targeted at legislators, who formulate laws, or at regulators who implement and enforce laws (J. M. de Figueiredo & Tiller, 2001; R. J. P. de Figueiredo & Edwards, 2007). It consists of strategically supplying these policy actors with relevant information (Baron, 2013). Firms lobby with the aim to persuade policy actors to opt for their policy preferences. Although there is no clear consensus in the literature on the effectiveness of lobbying on the performance outcomes of a firm (Hadani & Schuler, 2013), several studies pointed out the positive effects of lobbying by corporations on a variety of policy outcomes (Hadani, Bonardi, & Dahan, 2017). The underlying mechanism through which firms can generate gains with lobbying is that they increase barriers to entry, secure preferential treatment from policy actors, or safeguard them from external pressures (e.g. Hillman and Keim, 2005). For instance, studies conducted in the U.S. energy market showed that lobbying expenditures can influence the enactment of an energy policy (Kang, 2015), and had a positive effect on the increase in regulated prices (Bonardi, Holburn, & Vanden Bergh, 2006). Same results were found regarding regulatory prices in telecom (Duso, 2005). Other empirical studies show that lobbying had a positive influence on access to grants (J. M. de Figueiredo & Silverman, 2002), increased technology diffusion (Comin & Hobijn, 2009), and had a positive impact on the overall economic performance of a firm (Horgos & Zimmermann, 2009).

Alike the market environment, firms cooperate and compete in the political environment when lobbying politicians. That is, lobbying can be used by a firm to exclusively influence the institutional environment to its benefit (Dorobantu, Kaul, & Zelner, 2017), or it can be a pooled effort from various firms, that collaborate to alter the institutional environment in the benefit of all or a group of firms. Literature has long concentrated on the successful cooperative efforts between firms to influence public actors, and on the competition between firms' and consumers' interests. For instance, the literature points out that, when facing collective pressure, large firms are usually winners in the lobbying process, since they can access the highest-ranked political actors and have better capabilities to diversify their non-market strategies (Baumgartner, Berry, Hojnacki, Leech, & Kimball, 2009; Schuler, Rehbein, & Cramer, 2002). When issues are salient, firms adopt a collective strategy (Hillman & Hitt, 1999) and engage in a more aggressive political strategy (Getz, 2001). The rationale behind cooperation among firms in political markets is that it can reduce regulatory uncertainties (Kingsley, Vanden Bergh, & Bonardi, 2012), and lower the institutional costs for the firms in cooperation.

Insofar, competition between firms in political markets has been less explored in the literature. Studies in this field suggest that political markets are more attractive when there is less competition between demanders of policies (Bonardi et al., 2005, 2006; Bonardi & Keim, 2005). The rivalry between interest groups also implies high regulatory uncertainty, for which stakeholders pursue a multifaceted political strategy (Kingsley et al., 2012). Furthermore, it reduces the performance of a firm's non-market strategy, leading to a lower return on investment, as shown in the context of U.S. energy utilities, where regulatory utilities were less likely to implement their policy choice of increasing regulated prices when they face competition from interest groups advocating for consumers' interests (Bonardi et al., 2006). Lastly, under competition, lobbying efforts from firms counteract, and governments get closer to the welfare-maximizing policy (Alves, Brousseau, Mimouni, & Yeung, 2021; Gawande, Krishna, & Olarreaga, 2012).

Regarding the geographical concentration of studies on non-market strategies, the literature is mostly focused on U.S. cases. In Europe, studies on non-market strategies and, specifically, on lobbying are fewer. A possible reason is that, compared to the U.S., there are fewer data sources available. Research also highlights that lobbying in the European Union is more technical and more focused on the expertise of interest groups than in the United States (Bouwen, 2011). Furthermore, the EU political environment has its particularities. For instance, compared to the U.S. political environment, in Europe, organisations are not allowed to finance electoral campaigns. Thus, a common practice to lobby in the EU is responding to public consultations. A public consultation is a regulatory tool (often in the form of questionnaires) where regulators seek input from participants around a matter. Participants can express their views and priorities around a topic, and give information on new legislative proposals or existing laws. Empirical research concentrating on the European case finds that fragmentation on the demand side of the political market provided room for the European Commission to react to lobbying efforts impartially, in the context of the consultation for the EU wholesale roaming regulation (Alves et al., 2021).

Integrated strategies

Both market and non-market strategies can influence firms' performance. As mentioned before, market strategies can be defined as "a concerted pattern of actions taken in the market environment to create value by improving economic performance", and non-market strategy as "a concerted pattern of actions taken in the non-market environment to create value by improving its overall performance" (Baron, 1995). Yet, most of the research in these fields has developed them separately, implying that firms independently design their market and non-market strategies. In reality, firms recognize that, in some cases, where the non-market environment has a significant impact on an organisation's performance, it is in their best interests to integrate both strategies. For instance, to prevent entry to the market, incumbents could implement non-market strategies that increase regulatory barriers for new entrants, and subsequently increase their economic rents (Baron, 1997, 1999). "Integrated strategies" come to interplay when the non-market environment and market environment are bundled together for firms to succeed.

While the majority of research on integrated strategies is conceptual (Baron, 1995, 1997), a smaller stream of research empirically analyses how and when firms couple their market and non-market strategies. A study focusing on the U.S. electric utility industry, which faced considerable restructuring through mergers and acquisitions following federal deregulation reforms, found evidence that firms use election campaign contributions to politicians to influence merger approvals (Holburn & Vanden Bergh, 2014). Other research concludes that firms that possess higher non-market capabilities may use non-market strategies to offset competitive pressures and competition when facing higher costs or less demand (Marsh, 1998; Schuler, 1996).

A largely used theoretical perspective for understanding integrated strategies is the resource-based view (RBV). The RBV lens considers that firms can achieve a sustainable competitive advantage by having access to and exploiting tangible or intangible resources (Barney, 1991). In this perspective, firms can pool resources that integrate both market and non-market environments (Ahammad, Tarba, Frynas, & Scola, 2017; McWilliams, Van Fleet, & Cory, 2002), which result in valuable complementarities and represent a source of competitive advantage for a firm (Angwin, Mellahi, Gomes, & Peter, 2016).

In an innovation ecosystem context, where there is high uncertainty on the policies concerning the focal offer, engaging in an integrated strategy has the potential to bring complementarities to both the market environment and the non-market environment. Firms in an innovation ecosystem cooperate and compete in the market arena to produce the focal offer, by engaging in strategic, investment or R&D partnerships to develop the technology. Similarly, they employ individual and collective non-market strategies to lift regulatory barriers. Engaging in market partnerships can help actors gain access to the institutional actors more easily and effectively while engaging in collective lobbying with other members of the ecosystem can help them establish the market for the focal offer and gain rents.

4.4 Theoretical framework

We start by assuming that firms in an ecosystem have competitive tensions at the market and the non-market levels. We adapt the conceptualization done by Bonardi et al. (2005) where the political environment is viewed as a market for public policies. The demand side of such a market is constituted by firms seeking public policies that benefit their businesses, and the supply side is composed of politicians, in charge of issuing legislation. In this setting, firms use non-market strategies to influence the supply side of the political markets. Regarding our specific context, the European Commission constitutes the supply side, whereas car manufacturers, automotive suppliers, connectivity providers, service providers and telecom providers, form the demand side.

In this framework, we are interested in studying the behaviour of firms in the non-market environment, especially when they are allies in the market environment. In a context where innovations are at an early stage and based on the literature, we posit that firms can adopt collective sector strategies. Similarly, firms belonging to the same ecosystem have an interest that their value proposition thrives to gain a competitive advantage over other ecosystems. With the aim of positioning themselves in the market, we posit that firms belonging to the same ecosystem align in their non-market strategies. Finally, relationships among companies not only concern the development of the innovation but also with other types of actors, like trade associations, that interact with institutional actors. Firms pool trade association resources in the non-market environment.

We formulate the following hypothesis:

H1: Firms belonging to the same sector are more likely to align in their non-market strategies.

H2: Firms belonging to the same ecosystem are more likely to align in their lobbying strategies.

H3: Firms collaborating in the market environment are more likely to align in their lobbying strategies.

4.5 Data & Empirical Strategy

4.5.1 Data

We collected three different sets of data. The first set of data is the input gathered from the Public consultation on Recommendation on Connected and Automated Mobility (CAM). It has a total of 630 responses, of which 469 are from citizens and end-users, 137 from businesses and association businesses and 24 from public authorities. It contains the contribution of the main stakeholders in mobility, among which are all relevant car manufacturers and automotive suppliers.

The second set of data is on firms' ecosystems. A firm's ecosystem is composed of its strategic alliances, investment partnerships and memberships. We obtain the different types of partnerships between firms that responded to the public consultation on connected and automated mobility. This information is collected from the firms' web pages and press releases, which are retrieved from Factiva.

The third set of data corresponds to the lobbying costs of firms. This data is retrieved from the Transparency Register (TR), a database that makes visible the companies that seek to influence the legislative process in the EU, their interests, lobbying costs, budgets, and who in the organisation is communicating with the commission. There is no obligation to report to the TR. However, meetings between Commission representatives and organisations can only take place if organisations are registered in the TR database. From this dataset, we collect the lobbying costs for 2018, the year when the consultation took place. In case firms did not report lobbying costs for 2018, we took the value for the previous year available[4].

4.5.2 Empirical Strategy

To determine the alignment of firms' market and non-market strategies, we first draw the network of alliances in both the market and non-market environments. A network provides a snapshot of the relationships between the different actors participating in autonomous vehicle technologies, and the placement of their significance, rather than observing them separately.

We construct the non-market environment's network from the input of the EU public consultation on connected and automated mobility. As explained in the previous section, the consultation contains various questions that collect the points of view of different stakeholders participating in autonomous mobility around different topics of interest. Two main topics emerge from the consultation: cybersecurity and data protection. Thus, we construct a network for each of the two topics. To do so, we select key questions of the consultation and attribute them to each of the two topics. The division among topics allows us to have a clearer picture of the position of the different stakeholders, compared to the output from a single question. Table 4.1 shows the chosen questions per topic, and table 4.2 shows a snapshot of the responses from some of the key stakeholders.

We identify firms' non-market alignment in a topic by analyzing their responses to the set of

[4]8 out of 68 registered companies did not report the 2018 lobbying costs. Of the eight companies, seven reported the 2017 value, while the remaining one had data for 2016

CYBERSECURITY	Q.14	Do you think the car manufacturers should put forward measures to secure the connected and automated vehicle against cyber-attacks?
	Q.15	Which of the below actions should, in your view, be prioritized to increase cyber-security resilience of connected and automated cars?
	Q.43	Requirements for cybersecurity pre-market tests should be further enhanced at EU level.
	Q.44	Cybersecurity should be included in the scope of the EU framework establishing (product) liability rules.
	Q.48	Who should have the weight in bearing the responsibility for setting up cybersecurity safeguards for protection against cyberattacks?
DATA PROTECTION	Q.17	In-vehicle data may disclose information about you (e.g. driving habits, location data) and giving access to these data may result in individuals concerned being subject, amongst others, to differentiating pricing practices, targeted advertising, and alike or even refusal of services. Despite these risks, would you give your consent to access your in-vehicle data to private companies for developing more digital car services, such as parking slots or automotive navigation systems?
	Q.18	In-vehicle data may disclose information about you (e.g. driving habits, location data). Despite any potential privacy risks associated with the processing of your in-vehicle data, would you still give your consent to access that data to public authorities, e.g. for increasing road safety?
	Q.71	Specific guidance on how to implement existing data protection rules (e.g. General Data Protection Regulation, ePrivacy Directive) in the context of connected and automated mobility would be helpful.
	Q.75	Which of the below processes should be prioritised in relation to providing for the access to in-vehicle data once the data subject has given the authorization for the collection and the sharing of the data?

Figure 4.1: Questions selected from the CAM consultation, divided per topic

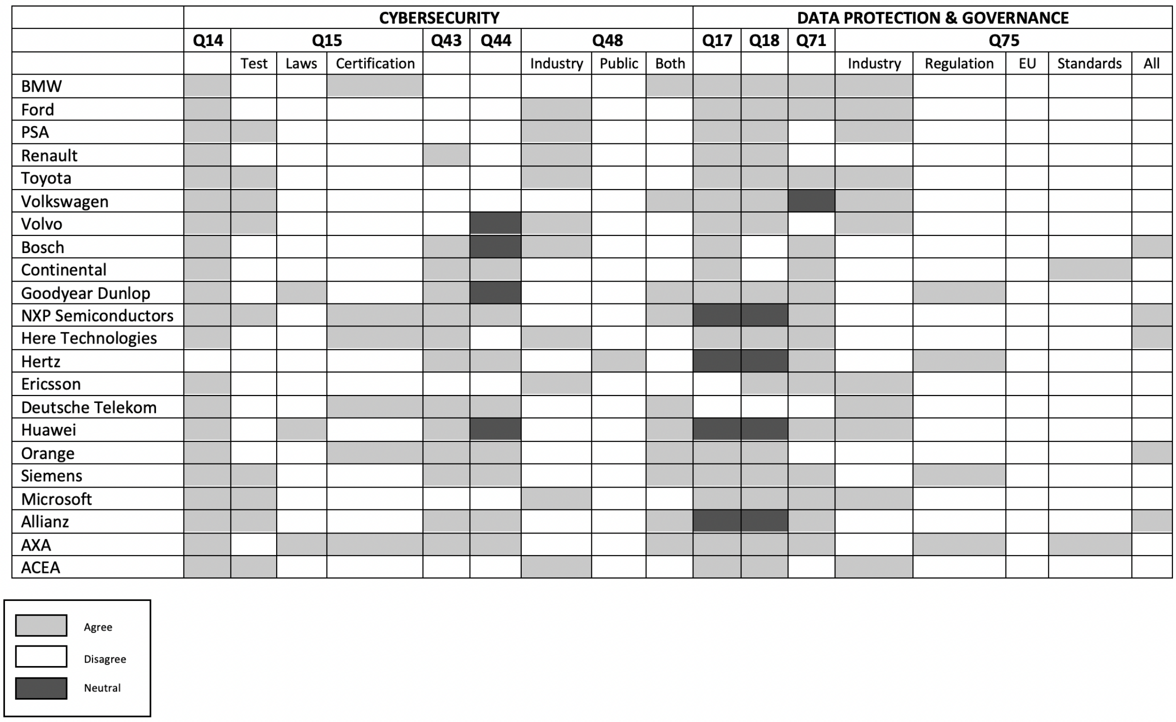

Figure 4.2: Consultation responses for key stakeholders

questions that belong to a topic on the consultation. Two companies are linked if they answered the same on, at least, one question associated with the topic. Accordingly, the *nodes* of the network are the stakeholders responding to the consultation and the *links* correspond to a common answer to one of the key questions of a topic. However, not all stakeholders are equally aligned. Some stakeholders respond equally more times than others. Therefore, we take into account the *weight* of the links among firms, which corresponds to the frequency that the two firms have the same answers on a given topic. The more the questions overlap, the larger the link's the weight between the two firms.

Similarly, we construct the market environment's network, by using the data on the different partnerships on automated mobility. Two firms are linked in the network if they have (previous to the date of the consultation), engaged in a partnership. The nature of the partnership can vary (i.e. they can engage in an investment partnership, strategic partnership, R&D partnership, consortium, or membership, among others). To avoid sample selection problems, we subset the data to the firms that have at least one partnership in the sample, which corresponds to 82 out of 104 firms.

By applying network analysis to the relationship among the various stakeholders in their market and non-market environments, we can obtain the position of actors in the networks and subtract relevant statistics. An interesting measure obtained from the network analysis is *modularity* since it allows us to determine the formation of communities regarding the lobbying behaviour in a network. Modularity measures the structure of the network regarding the strength of division of the nodes into different modules, clusters or communities. Networks with high modularity have dense connections inside the module, but scant links between nodes from other modules. We obtain the different modules created from Gephi, according to the methodology proposed by Blondel, Guillaume, Lambiotte, and Lefebvre (2008).

After constructing the networks and obtaining the relevant statistics, the output will consist of a pairwise dataset of all the possible matches that could occur in the bundle of firms who participated in the consultation. We use the resulting data from the network to run a logistic regression to determine the likelihood of firms belonging to the same module or community in the non-market environment, with respect to different factors, such as alignment in the market environment, among others. We wish to estimate the following regression:

$$log(\frac{\pi}{1-\pi}) = \alpha_{ij} + \beta_1 sector.alignment_{ij} + \beta_2 ecosystem.alignment_{ij} + \beta_3 trade.partnership_{ij} + \gamma Z_{ij} + \epsilon_{ijt} \quad (4.1)$$

where i and j are firm i and j respectively ($i \neq j$), t is the topic, $Pr(lobbying.alignment_{ijt} = 1) = \pi$ and Z is the vector of control variables.

The following variables are included in the regression:

Dependent variable: Our dependent variable, *lobbying.alignment* captures the non-market alignment of firms, and it is obtained from the measure of modularity of a network. It is a binary variable, that determines whether two firms belong to the same module (also cluster or community), where 1 means that firms belong to the same cluster, and zero otherwise.

Independent variables: Four variables are considered to capture the market alignment of firms: (1) The variable *ecosystem.alignment* captures whether firms belong to the same ecosystem. It takes the value of 1 if a pair of firms have engaged in a partnership, and zero otherwise. (2) The variable *trade.partnership* captures whether firms partner with a trade association. It takes the value of 1 if a pair of firms have engaged in a trade association partnership, and zero otherwise.(3) The variable *partnership* measures whether firms engage in any kind of collaboration (strategic partnership, investment, supply relationship, among others). It takes the value of 1 if a pair of firms collaborate, and zero otherwise. (4) The variable *sector.alignment* measures whether firms participate in the same sector. It takes the value of 1 if a pair of firms' main activity is in the same sector, and zero otherwise.

Controls: We include additional variables that can also affect the non-market alignment of firms. Firstly, we control for the geographical location of the pair of firms. the fact that the headquarters of a pair of firms are located in the same country might influence their non-market alignment due to shared regulatory practices, or cultural biases. We include the variable *same.country*, which takes the value of 1 if two firms are located in the same country and zero otherwise. Besides, we control for the firm size. Larger firms might have different interests than smaller firms since they have more bargaining power over the regulator and different issues regarding competition in the market. We include the variable *same.size*, which takes the value of 1 if the pair of firms have the same size and zero otherwise)[5]. We also control for the fact that the pair of firms are subscribed to the TR database, a database that lists organisations that lobby the European Commission, and reports their interests, the budgets, and who is in charge of the communication with the commission. This variable works as an indicator of the lobbying investment in Brussels. Firms have incentives to register if they want to obtain 1-to-1 meetings with commissioners. Thus, belonging to the TR database is a proxy for access to public actors. The variable *both.in.TR* takes the value of 1 if the two firms are registered in the TR, zero otherwise.

4.6 Results

Initially, we graphed the network resulting from the different market alliances between actors in our sample. Results from this network are portrayed in figures 4.3 for the ecosystem partnerships and 4.4 for all partnerships combined. As said before, firms working on autonomous vehicles cannot innovate by themselves. They see to ally with other firms, where each can draw on their capabilities and create the autonomous vehicle. We can observe that the most central actors in this network are large firms, especially car manufacturers and automotive suppliers (i.e. Bosch, Ericsson, Volkswagen, BMW). Car manufacturers and automotive suppliers, who are incumbents in the market are interested in creating these types of alliances to not be left behind in the innovation process. Since they leverage a vast amount of resources and possess knowledge of the industry, they are able to attract different partners from other industries.

Next, we graphed the networks resulting from the responses to the consultation on the topics of cybersecurity and data protection and governance, as described in the previous section. Figure C.3, in appendix C, depicts the network of lobbying alliances on the topic of cyberse-

[5]We have four size categories: small firm, medium-size firm, large firm, very large firm.

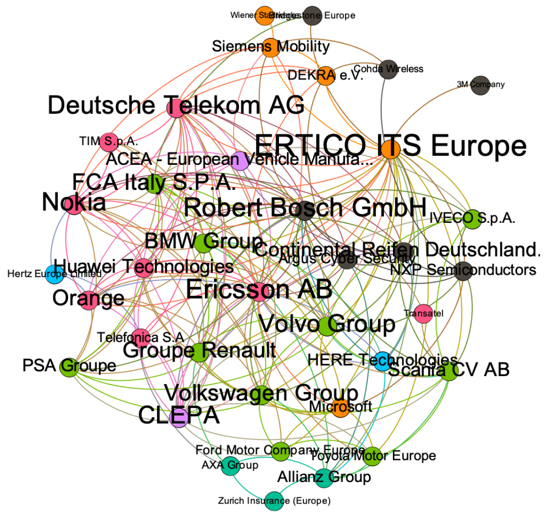

Figure 4.3: Ecosystem Graph

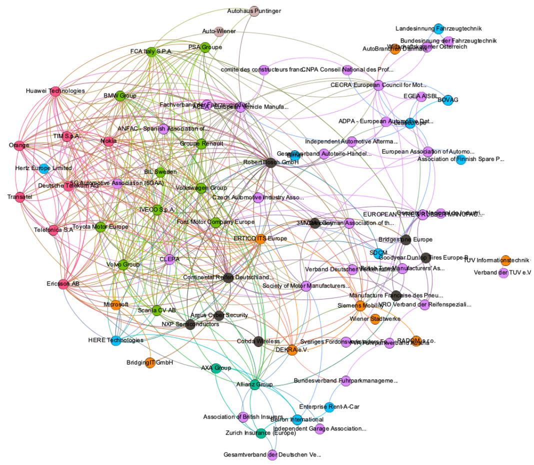

Figure 4.4: Partnership Graph

curity and figure C.4, in appendix C, depicts the network of lobbying alliances on the topic of data protection and governance[6]. Graphs' colours indicate the different sectors of the firms in our sample[7]. The network visualization provides an intuition of the tight relationships that exist among the different sectors. In both graphs, we can notice a cluster formation among different industries, which is the case for car manufacturers and automotive downstream market suppliers. Telecom providers are more scattered along with the graphs.

Network statistics are portrayed in tables C.1 and C.2 in appendix C. From these tables, we first observe that the average path length for the cybersecurity network is equal to 1.129, which implies that, on average, to reach the farthest node of the network, it takes up to 1.129 connections. For data protection, the average path length is 1.11. Nodes have a high number of neighbours, corresponding to an average degree centrality of 70. 54 and 71.63 neighbours, for cybersecurity and data protection networks respectively. The less connected node has 88 neighbours, while the highest connected node has 104. If we consider the weights of the network, the average weighted degree is 160.22 and 202,61 neighbours for cybersecurity and data protection networks respectively. We can also observe the companies with the highest weighted degree

[6]We use Gephi, a network visualization software, to create the graphs and the Force Atlas layout algorithm to spatialize it. Force Atlas positions the nodes by simulating physical forces of attraction and repulsion, where nodes repulse each other like charged particles, but edges attract them. Two nodes are closer to each other when they are connected, and farther when they are not. This algorithm is useful to visualize communities.

[7]Light green for car manufacturers, blue for automotive downstream market suppliers, brown for automotive suppliers, fuchsia for telecom providers, pink for vendors, violet for trade associations, and orange for other actors

and closeness centrality.

To observe the presence of clusters or communities within each graph, we calculated the *modularity* of the networks. Modularity measures the strength of division of a network into modules, clusters or communities. Networks with high modularity have dense connections between the cluster, but scant links between nodes from other clusters. Figures C.1, and C.2, in appendix C, show the cybersecurity and data protection & governance networks divided by the different modules. According to this approach, we obtain the presence of 3 different clusters, assigned by three different colours (green, purple and orange). The network visualization of communities gives us a hint that some of them are organized within companies from the same sector. However, the relationship between factors like market partnerships and ecosystems, among others, is less straightforward.

After the graph exploration, we perform a logistic regression analysis to understand the factors that increase the likelihood of firms to align in the non-market arena, and more specifically, on the creation of communities. The results from the logistic regression model are displayed in 4.1. Models 1 and 2 correspond to cybersecurity, and models 3 and 4 correspond to data protection and governance. In models 1 and 3, we separate the types of partnerships related to ecosystems and trade associations, while models 2 and 4 bundles all partnerships. Firstly, we observe that for both topics, belonging to the same sector increases the likelihood of firms to align in their non-market strategies, confirming hypothesis 1. Firms have the interest to align in their lobbying strategy when they belong to the same sector. For example, regarding cybersecurity topics, almost all car manufacturers prefer that industry actors are held responsible for setting up cybersecurity safeguards for protection again cyberattacks. On the contrary, most of the automotive downstream market suppliers push for public responsibility, and a few advocates for both industry and public to be held responsible. In addition, car manufacturers believe that tests, before vehicles go to market, are the priority to increase the cybersecurity resilience of autonomous cars, instead of cybersecurity by design, laws or certification processes. Regarding data protection and governance, the same pattern is observed. We find some examples of sector alignment in this topic in the consultation answers. For instance, all car manufacturers prefer that industry-led approaches, such as contractual arrangements and voluntary standardization, should be prioritized for accessing the data, instead of regulatory measures, EU guidance or standardization. On the contrary, automotive downstream suppliers prefer regulatory approaches imposing a legal obligation to access the data.

Additional text-based responses to the consultation also provide us with qualitative information that confirms sector alignment. When expressing their concerns with sharing data, car manufacturers signalled that they are not opposed to sharing their data if it is through the "Extended Vehicle Standards", which are international standards developed by car manuacturers themselves. For instance, the PSA group (now Stellantis) responded "This could be done with personal and non-personal data depending the case, anyway it needs to fulfill all GDPR requirements. Direct access to in-vehicle data from several sources result in safety and cybersecurity problems plus an overview is missing to whom is given access to data and what is done with it. Sharing data is essential to innovation and to the further development of mobility. To make it possible we are willing to ensure safe and secure off-board access to vehicle data through Extended Vehicle. Direct third-party access to the vehicle for remote data access during normal vehicle operation is likely to carry negative effects and must be avoided. Giving any third party access to a vehicle would create serious issues: data privacy, vehicle security, product liability, fair competition". Similarly, Volkswagen expressed that "Volkswagen is willing to share in-vehicle data. Access to such data needs to happen in a responsible, safe and secure manner, in line with relevant legislation such as data protection and liability rules. Hence, access to in-vehicle data does not mean in-vehicle access. The Extended Vehicle and Neutral Server models show how access to vehicle data can practically be granted safely and securely while safeguarding customer choice and privacy" (European Commission, 2019).

We also observe a positive and statistically significant coefficient for the ecosystem alignment variable for both topics, confirming hypothesis 2. Indeed, firms that cooperate in the market arena to develop a focal offer, also tend to align in the non-market arena, showing that firms do engage in integrated strategies. This result follows the rationale that in an innovation ecosystem, with high uncertainty on the policies that will affect the focal offer, firms employ market and non-market strategies that can help them favour the institutional solution that allows them to secure their investment and capture the more rents. One example is HERE Technologies and Bosch. Bosch invested in HERE Technologies and both companies engaged in a strategic partnership to provide an open platform and customer-centric solutions for automotive and IoT. The companies have similar responses on both cybersecurity and data protection and governance topics, (i.e. on the requirements for pre-market tests, the consent to access to data, and the processes to be prioritized for the access to in-vehicle data, among others).

The coefficient for the interaction term *ecosystem.alignment=1:samesector=1* is positive and significant, meaning that there is a higher likelihood of alignment for firms belonging to the same ecosystem and the same sector. We can deduce that for firms that do not engage in an ecosystem alliance but do belong to the same sector, the likelihood of lobbying alignment is lower. The same can be deduced for firms that do not belong to the same sector but belong to the same ecosystem. Furthermore, when bundling all partnerships together, as shown in models 2 and 4, results also indicate that a partnership increases the likelihood of lobbying alignment, confirming hypothesis 3. Partnering with a trade association has a positive and significant relationship with lobbying alignments. This is a straightforward result since trade associations represent the interests of the industry through different public engagement activities.

Another interesting result is to observe the differences between the two topics in the regression results. Coming from the same country increases the likelihood of firms aligning in their non-market strategies on the data protection and governance topic. We believe this is because data protection and governance is a topic with an intricate institutional focus at a national level. In Europe, data protection laws are enforced through Data Protection Authorities (DPA), which are independent public authorities tasked with overseeing the implementation of data protection legislation. They offer expert advice on data protection concerns and manage complaints about violations of the General Data Protection Regulation (GDPR) and other national laws. Each EU member country has one DPA, for instance, in France it is the *Commission Nationale de l'Informatique et des Libertés - CNIL*. These authorities can then issue nationwide laws that are in line with European laws, such as the *Loi Informatique et Libertés* for the French case. However, there are heterogeneities in the stringency of the implementation of these laws at a national level. Thus, firms from the same country will tend to align as they design their compliance mechanisms according to domestic regulatory frameworks. On the other hand, having the same size increases the likelihood of firms aligning their non-market strategies on cybersecurity topics. Since the topic of cybersecurity is highly technical, the question of capacities comes into interface when comparing larger and smaller firms. Indeed, large firms have more capacities to tackle this issue and share the interest of maintaining their market position, which makes them align in their non-market strategies. For smaller firms, this issue may be more difficult to face, due to its technical complexity.

Contrary to expectations, subscribing to the transparency register has no significant effect on the likelihood of firms aligning in their non-market strategies on cybersecurity or data protection & governance topics. Since consultations are an easily accessible tool to communicate with the commission, we believe that firms do not see the immediate accessibility leverage from other firms to inform commissioners.

4.7 Conclusion

In this paper, we examine how firms integrate market and non-market strategies in the context of the development of an innovation, the autonomous vehicle. To develop an autonomous vehicle, multiple firms that are inherent competitors or belonging to different sectors are encouraged to collaborate. Thus, they not only depend on their performance, but also on the performance of their ecosystem. Our premise is that firms engage in integrated market and non-market environments, that is, they align their lobbying interests with their partners in an ecosystem, as they expect ecosystems to thrive and the innovation to materialize. We hypothesize that firms are more likely to align in their non-market strategies when they collaborate in the market environment. We perform our analysis in the context of the EU consultation on connected and automated mobility. Two topics are salient in the consultation: cybersecurity and data protection & governance.

In this setting, we analyse the responses of the consultation by performing a network analysis to map the different communities that emerge from the responses regarding the two topics selected. We then perform a logistic regression analysis in order to determine the likelihood of firms aligning in the non-market environment (i.e. belonging to the same community in the network) having formed market alliances. Results confirm our hypothesis that firms tend to

Table 4.1: Likelihood of firms of aligning in the non-market environment

	Dependent variable: lobbying.alignment			
	Cybersecurity		Data protection	
	(1)	(2)	(3)	(4)
ecosystem.alignment=1	0.422**		0.643***	
	(0.176)		(0.175)	
partnership=1		0.666***		0.890***
		(0.123)		(0.123)
trade.partnership=1	1.183***		1.196***	
	(0.150)		(0.152)	
sector.alignment=1	0.343***	0.287***	0.645***	0.656***
	(0.097)	(0.103)	(0.095)	(0.100)
samecountry=1	0.159	0.143	0.311**	0.287**
	(0.127)	(0.127)	(0.125)	(0.126)
samesize=1	0.379***	0.338***	0.030	0.004
	(0.089)	(0.087)	(0.091)	(0.089)
both.in.TR=1	0.073	0.079	−0.029	−0.023
	(0.080)	(0.080)	(0.079)	(0.079)
ecosystem.alignment=1:sector.alignment=1	0.773**		0.716*	
	(0.372)		(0.384)	
partnership=1:sector.alignment=1		0.655**		0.187
		(0.257)		(0.256)
Constant	−1.046***	−1.023***	−0.929***	−0.927***
	(0.062)	(0.062)	(0.061)	(0.061)
Observations	3,321	3,321	3,321	3,321
Log Likelihood	−2,038.775	−2,046.207	−2,056.681	−2,063.493
Akaike Inf. Crit.	4,093.551	4,106.414	4,129.361	4,140.986
Note:			*p<0.1; **p<0.05; ***p<0.01	

align their responses to the EU consultation with firms with whom they have partnered to develop the autonomous car. Besides, our findings show that firms are more likely to cooperate in the market arena with other firms from the same sector. This result is accentuated when firms from the same sector also belong to the same ecosystem, showing even further the integration of market and non-market environments of firms. We also observe differences between the two topics. Results indicate that organisations based in the same country tend to align in the lobbying for data protection and governance issues, but not in cybersecurity. However, having the same size does influence alignment when lobbying for cybersecurity, compared to no effect on data protection and governance issues.

From these results, we highlight multiple implications for the actors participating in the AV ecosystem. Firstly, organisations tend to favour the institutional solution that allows them to secure their investment in the focal offer. They align their lobbying strategies with other actors in the ecosystem since it allows them to capture the value created by the innovation process. Secondly, organisations align with others from the same sector despite being competitors. For example, through sector alignment, some actors, notably car manufacturers, can push for private approaches to data standardization. This means they will be able to self-regulate vehicle data standards, which could probably mean gatekeeping data from other actors, and putting less stringent rules regarding consumer protection issues. Firms from sectors other than car manufacturing, notably, automotive downstream market suppliers, prefer public-led regulatory approaches as they can have more leverage to access data that car manufacturers might gatekeep. Thirdly, firms have an interest in aligning with others based in the same country when it concerns a topic that is more institutionally anchored, like data protection and governance. This is because firms design their technologies according to domestic regulations. Fourthly, large firms have an interest in aligning with other large firms for topics with a more technical background. They generally possess the capacities to tackle technical issues compared to smaller firms. Lastly, public actors should take a deeper look at stakeholders' strategies in the market and non-market environments to frame their policies and regulations. On one hand, tools like public consultations are important to take into account since they can help gather information on the challenges and potential risks of non-adapted regulations with respect to innovations.

Through these tools, policymakers are interested in understanding the majority alignment to dictate rules that favour them. On the other hand, coalitions should be taken into account when analyzing the responses to the public consultation since larger alignment on a policy choice does not necessarily imply that it is the most optimal, but rather that private actors are strategically behaving to favour their interests.

This study has various limitations. Initially, we do not analyse the viewpoint of public actors and other types of institutions (academic, general public), nor the decision of the commission concerning AV cybersecurity and data protection & governance. It could be interesting to comprise the perspective of other actors and the alignment of the commission's decision with the different firms. In addition, since the AV market is in its early stage, we are not able to capture the lobbying dynamics at further stages of the innovation. Further research could focus on grasping the dynamic factor when looking at non-market strategies of firms in an innovation context. In this work, we do not observe other possible mechanisms used for lobbying, such as the number of internal meetings that firms have with commissioners. Further work can include these other mechanisms to have a more complete perspective of the non-market strategies employed. Besides, the EU consultation on connected and automated mobility launched in 2018 focused primarily on two topics: cybersecurity and data protection & governance. Other topics of relevance concerning ethical dilemmas, other safety issues, liability, the link with public transport, and technological challenges were not covered in this consultation. Further work can try to analyse the alignment of the market and non-market strategies with the use of more topics.

CONCLUSION

This dissertation aims to respond to the following question: "*How do actors participating in the electric and autonomous vehicle development shape their strategies to scale-up innovations in an interdependent, infrastructure-dependent and regulatory-uncertain market?*". To answer this question, I have taken different angles, which inspired three different research projects, each of which corresponds to a chapter of this thesis.

Chapter 2 analyzes firms investment strategies to deal with diverging interests in a coopetitive environment. The strategies involve cooperating to resolve bottlenecks while dealing with competitive dynamics among themselves. Both incumbent firms and startups are interested in resolving bottlenecks, since they may constraint the overall growth of the ecosystem, due to poor performance, poor quality or shortages. However, startups face the risk of misappropriation of their innovation when forming alliances with incumbent firms. We built a novel database on corporate venture capital (CVC) partnerships between incumbent firms and startups on the autonomous vehicle ecosystem formed in the U.S. between 2009 and 2018. We demonstrate empirically that CVC programs direct their investments towards startup firms producing bottleneck components. Our results suggest that equity-based ties are more likely for startups that develop bottleneck components. We also demonstrate the existence of competitive forces that emerge in CVC investor-investee interactions. Equity-base ties are more likely for startups with a higher patenting activity, with more links to influential third parties, and having a more mature innovation.

Chapter 3 empirically addresses the infrastructure barriers in the mass-deployment of electric vehicles, and evaluates the strategies undertaken by policy-makers and private stakeholders, notably car manufacturers and infrastructure-service providers, to increase electric vehicle adoption. Given that Battery Electric Vehicles (PEV) and Plug-in Hybrid Electric Vehicles (PHEV) offer a promising choice to provide a low-emission transport solution, governments, automotive manufacturers, and charging infrastructure operators have deployed market-boosting initiatives to incentivize purchases. However, EV uptake has been slow. We analyze the relationship of the factors that represent an obstacle to PEV adoption and the different incentives in place on adoption. We built an original database and statistically analyze the relationship of 14 socio-demographic, technical, and economic factors on BEV and PHEV market shares, separately, in 94 French departments from 2015 to 2019, using mixed-effect regression. We find that fast and ultrafast charger density boost BEV sales, while slow-and-normal charger density leads to higher PHEV sales. Subsidies, relative to vehicles' prices, are positively correlated with BEV sales, but not with PHEV sales. Other factors are also found to be relevant for BEV/PHEV adoption, like the number of available models or the decrease of electricity prices, compared to gasoline prices.

Chapter 4 discusses the alignment of firms in their non market strategies when they are cooperating in their market strategies, especially through the creation of an ecosystem. That is, we determine firms' willingness to engage in integrated strategies. We perform this analysis with data from the EU public consultation on connected and automated mobility. Through this consultation, firms could inform their preferences regarding two main topics related to autonomous driving: cybersecurity and data protection. We empirically test for the presence of an alignment, in cybersecurity and data protection issues, by analyzing the common responses of firms to the EU consultation for each of the topics. We perform a network analysis to determine which firms belong to the same cluster when responding to the consultation. We then perform a logistic regression to determine the factors that were interrelated with non-market alignment. We find that firms are more likely to align in their non-market strategies when they belong to the same ecosystem for both cybersecurity and data protection topics. We also find that firms belonging to the same sector align in their non-market strategies. Belonging to the same country is relevant for data protection issues, while having the same size is relevant for cybersecurity issues.

In what follows, I examine the theoretical and empirical contributions of this dissertation. Then, I present some limitations of this dissertation, and point out future avenues for research. Finally, I discuss policy and managerial implications of this research.

Contribution

Firstly, this dissertation contributes to the knowledge on electric and autonomous vehicle development. Both innovations have similar particularities that could potentially revolutionize the mobility industry. However, a narrow view of these technologies would not manage to capture the various challenges of the innovations. By doing a general overview of the history, state-of-the-art, the promises and the perils of these innovations, I identify the main barriers for the deployment of the technology. Three fundamental barriers for the deployment of electric and autonomous mobility are: the divergence of interests between stakeholders, infrastructure barriers and regulatory barriers. One of the main takeaways for the development of electric and autonomous vehicles is that, to resolve barriers, firms will collaborate with others that hold the knowledge on the bottleneck component. Another takeaway is that for the deployment of the technologies, infrastructure needs to be developed in parallel. Stakeholders shouldn't wait to invest in infrastructure, as it is a crucial factor for the adoption on the innovations. Especially, in the case of battery electric cars, the focus should be on the installation of fast and ultrafast charging.

History has been filled with stories of innovations that failed to establish themselves in the market for reasons other than their performance. The electric vehicle is a fitting example of this phenomenon. In the 19th century, internal combustion engine vehicles won the race against EVs partly because of the network of roads and gas stations installed in the routes. Nowadays, we see the reemergence of EVs, and we can observe their potential to decarbonise mobility at a large scale. Governments around the world have interest in the deployment of electric and autonomous car, since they are key to fulfill their environmental targets. For example, the European Green Deal and counts heavily on the adoption of electric vehicles to reach emission reduction objectives.

However, as highlighted in this research, private stakeholders face several barriers that could impede innovations in mobility to scale-up, and refrain private actors from participating in the market. For example, charging infrastructure installation, specially fast and ultrafast charging infrastructure, requires high investments. Without a sufficient mass of EVs, car manufacturers, charging point operators and mobility-as-a-service providers have low incentives to install the infrastructure and provide the service. In addition, the lack of regulation in these nascent markets results in diverse business models and supporting technologies, which could create inefficiencies, since there is no consensus on the requirements for the service provision. For electric vehicles, these sub-markets correspond to the charging of the vehicle, i.e. battery swapping, charging stations, or improving the capacity of the battery itself. When markets fail or struggle to organize, governments could take part as orchestrators of the market. This raises the question: Should the government favor the adoption of innovations to serve the public interest? (Deleidi & Mazzucato, 2021)

Prior literature suggests that when innovations compete, at some point the system will lock in one of the two competing technologies (Arthur, 1989). The lock-in occurs when every newcomer in the market chooses this technology, despite her preference for the alternative. The order of events in the selection of the technology is also important. For instance, the order of arrival of a set of agents influences the final outcome from the competition among innovations. In this competition, not necessarily the best technology wins. This is for example the case of the QWERTY typewriter and the VHS video recording system, where the market locked in an inferior technology compared to their alternatives. In the electric vehicle market, the clear differentiating factor between EVs and ICEVs is infrastructure. As a crucial factor for adoption of electric vehicles, infrastructure becomes a priority to promote mass-adoption, and governmental involvement will be crucial at its orchestration.

This dissertation also contributes to the nascent empirical research on ecosystems. Previous literature treats bottlenecks as isolated events. However, taking into account the interdependencies among firms, through the creation of ecosystems, allows us to understand the cooperation and competition challenges in a highly interdependent setting, where the stakeholders have diverging interests. By taking the case of the autonomous vehicle ecosystem, we observe the unexplored interplay between ecosystems and corporate venture capital. We identify that firms use CVC to resolve bottlenecks within their ecosystem. We also contribute to this research by adding the non-market dimension. Firms that interact in the non-market environment create tacit alignments with other firms within their ecosystems.

We also contribute to the literature on strategic management, as we observe that cooperation, in a competition context, is highly valuable when firms develop components that represent bottlenecks for the ecosystem. Nonetheless, they use intellectual property protection mechanisms to protect themselves from coopeting firms. In the non-market arena, an important finding is that non-market strategies should be understood as individual, but also collective, when it comes to boosting an innovation.

Finally, this dissertation uses novel data that, given the early stage of the market, adds value to the ecosystems and strategic management fields, and to the transportation context. These sets of data consist of ecosystem formation through CVCs, and strategic partnerships, on bottleneck components, on non-market strategies of firms in the European context, and on socio-demografic, economic and technical factors that have the potential to impact electric vehicle adoption.

Policy implications

A key policy implication concerns the role of the government on the adoption of innovations. First of all, governments should provide economic incentives, such as subsidies and registration tax reductions to the purchase of electric vehicles. These policy incentives can be implemented at a national or at a local level. Similarly, governments can provide disincentives to the purchase of ICE vehicles, such as the implementation of a carbon tax that would increase gasoline prices and make ICEVs more costly for the users. However, increasing the carbon tax can lead to social movements, as it was the case of France with the "Yellow Vests" movement, pushing the French government to suspend additional taxes on fossil-fuels prices. When designing policies, governments should discuss their effects on the population, especially in the low-income households, and devise redistribution mechanisms for the affected population.

Secondly, governments should play a more interventionist role by orchestrating the role of public charging infrastructure. Governments should encourage private actors to install ultra-fast charging in highways or EVs, fast charging in urban areas for EVs, and slow and normal chargers for PHEVs. Using instruments like public tenders, they can organize the charging infrastructure market by providing incentives to private actors to participate in the infrastructure's operation and service deployment, and serve the public interest of decarbonation.

Lastly, regulators can help define the market by defining clear rules for the deployment of innovations. We observed that stakeholders in the autonomous vehicle ecosystem have diverging interests with respect to sensitive topics like cybersecurity and data protection. However these sets of rules need to be designed by taking into account the behaviour of stakeholders when lobbying to regulators. Indeed, regulators and policy-makers should take into consideration that partnerships between organisations could explain their lobbying strategies. Public consultations are useful tools for institutions to receive input from organisations subscribed in different industries and with different characteristics. Based on these tools, regulators and policy makers tend to favor the option that favors the majority of the actors. However, it should be taken into account that firms strategically combine both their market and non-market strategies. Therefore, an institutional solution that favors the majority is not necessarily the best one.

Managerial Implications

In recent years, the potential for both electric and autonomous vehicle technologies has gathered the attention of multiple actors from different sectors. However, actors recognize the barriers for their implementation. They have high stakes to win, but also high stakes to loose, given the potential for value creation but the high costs for their development.

The first managerial takeaway is that stakeholders should cooperate in order to participate in the market, since they do not have all the competences to innovate by themselves. A possible instrument for firms to cooperate with others, notably startups specialized in the development of the technologies, is corporate venture capital. This instrument is even more crucial to utilize when accessing a bottleneck component. Through this type of collaboration, organisations can resolve the bottleneck and make the ecosystem evolve.

Cooperation is not only crucial in the market arena, but also in the non-market arena. As highlighted in the results, in the early stage of the deployment of innovations, firms have incentives to align with their ecosystem partners to create value within the ecosystem. For large firms, putting this result in practice is rather evident. They are aware of their coalitions in the market environment when lobbying the regulator and they have sufficient instruments to put in place sophisticated non-market strategies. However, for small firms, developing effective non-market strategies within an ecosystem might be more complex. Small firms should be aware of the lobbying capabilities of their ecosystem and take advantage of it.

On the other hand, cooperation can bring risks of misappropriation of the innovation, since large firms have interest in having information on the startup's main asset, which is the innovation per-se. In this case, startups can protect themselves from misappropriation through the use of formal (i.e. patents) and informal mechanisms (i.e. maturity of their innovation and connections to influential third parties) to avoid misappropriation.

Lastly, this dissertation highlighted several factors that motivate potential adopters of electric vehicles to purchase them. One of the factors is the availability of EV models. The underlying mechanism is that higher availability of models can increase awareness in potential users and the brand visibility of the manufacturer. Therefore, car manufacturers could increase their EV sales by providing a larger set of EV models, with different sizes, styles, battery capacities, and designs. This recommendation implies incurring in R&D and manufacturing costs but they could gain new customers and it could help a firm to differentiate from its competitors.

Limitations

I acknowledge that this dissertation has some limitations. In this work, we provide a panorama of the strategies undertaken by stakeholders in the electric and autonomous mobility ecosystems to scale-up innovations. Despite the use of different perspectives in both the private and public spheres, not all the crucial stakeholders are considered in this research. That is the case of some local public entities and energy providers, among others. For example, municipalities, which are not considered in this research, play a key role in scaling-up innovations in mobility. Municipalities' strategies include engaging in mobility projects with private actors to improve their public transport service, among others, and they enable the testing and inclusion of electric and autonomous cars on their urban perimeter. Similarly, some of the strategies used by actors participating in the market are not considered in this research. For instance, incumbent firms use other instruments, aside from corporate venture capital programs, to resolve technological bottlenecks, such as strategic alliances, R&D alliances, or acquisitions. The role of these strategies on the resolution of coopetition issues is not explored in this research.

Innovations are subject to external factors that can change the success or failure in their implementation. We observed throughout the history of electric vehicles that the technical performance, generally a key factor in the choice of vehicle types, was not relevant in the 1930's for the choice between internal combustion engines and electric cars. Instead, the creation of an ecosystem surrounding the internal combustion engine vehicle, that reunited the construction of roads, and the installment of gas stations along the roads, contributed to the prevalence of ICEV engines over EVs. Similarly, I do not capture the role of other competing technologies in this research. For example, I do not consider the role of hydrogen vehicles relative to electric cars, nor the advances in biofuels or improvements in fuel efficiency of ICE vehicles. This issue has implications in the strategy of stakeholders participating in the EV ecosystem because they are not only competing with companies proposing alternative technologies, but also because they might diversify their activities and participate in the ecosystem for the alternative innovation.

Nonetheless, competing technologies also face technical and socio-economic disadvantages. Hydrogen vehicles, or fuel-cell electric vehicles (FCEV), encounter several barriers that could hinder their deployment. Firstly, FCEVs endure higher energy losses compared to EVs. Energy efficiency for hydrogen vehicles can vary between 15 to 54%, from the production of electricity through electrolysis until it is converted to horse-power for the vehicle. Even considering technological advances in hydrogen energy efficiency, FCEVs need 2.5 to 3 times more energy than battery-electric vehicles (Bigo, 2020; European Federation for Transport and Environment AISBL, 2018). The cost of hydrogen vehicles is also significant. The total cost of ownership of an FCEV is 40-90% higher than for an ICEV and a BEV, though forecasts suggest it will be lower by 2026 (Ballard & Deloitte, 2020). They also require a network of refueling stations for hydrogen-powered cars, confronting a similar chicken-and-egg dilemma as battery electric vehicles. There is also a higher risk in the deployment since hydrogen is a highly explosive gas. Though hydrogen is already used for industrial purposes or for heavy-weight transportation (i.e. maritime transport), the risk of flammability is higher for personal light-duty vehicles. Last but not least, 94% of hydrogen production is done through fossil fuel energies, through steam reforming, liquid hydrocarbon oxidation or coal gasification (Ballard & Deloitte, 2020;

Bigo, 2020). Countries and regions in the world are aware of the advantages and disadvantages of the competing decarbonisation technologies for personal light-duty vehicles, and some of them have already started favoring either one of the many technologies. The choice of Europe is clear. In its Sustainable and Smart Mobility Strategy, the EU supports mostly battery electric vehicles and plug-in-hybrid electric vehicles instead of fuel-cell electric vehicles for light-duty road transport. Several projects are in place to increase incentives for EV adoption, and EU member states are launching public tenders for the installation of EV charging infrastructure plans to increase the network in European roads.

The reproducibility of this study is another potential limitation. Although other innovations have similar characteristics regarding the high interconnection among stakeholders, or the high regulatory uncertainty, some of the issues that electric and autonomous vehicles face are singular. In particular, they entail the usage of a scarce resource: land usage. Due to the potential of these innovations to reduce car ownership and completely change the urban dynamics, issues regarding the installation of infrastructure, the allocation of roads, the distribution of urban space, are issues that are unique of mobility. This has an influence on the behaviour of different stakeholders and the strategies used. Furthermore, we cannot generalize our findings to another regional or national context, aside from the ones already covered in this research, due to institutional, cultural and socio-demographic differences.

The road ahead for future research

This dissertation sparks different research avenues that are worth exploring along with the evolution of electric and autonomous mobility. One of the promises of electric and autonomous mobility is the fact that they can create synergies with public transport to transform the way people move and the way cities are organized. At the moment, municipalities are pushing for multimodality solutions between the different transport forms to propose a more efficient public transport that can replace car-ownership. Yet, very few studies have concentrated on the analysis of multimodal solutions and their actual impact in urban spaces. Therefore, questions related to the market design, business models, effectiveness and impact of multimodality solutions ase a clear path for future research. One of the characteristics that makes transportation an unique field to study is that it entails the usage of land, which is a scarce resource in urban spaces. Given that electric and autonomous vehicles represent an opportunity to reduce car ownership, new questions regarding the utilization of space spark from this dissertation. Besides, these innovations require the installation of infrastructure and the allocation of roads. It is interesting to analyze the means by which urban spaces will adapt to the entry of innovations.

As depicted in the technological cycle, uncertainty reduces through time and innovations either establish or perish. Firms' strategies change through time with the constitution and maturing of an ecosystem. The logic of value creation that we observed in the results of this dissertation can switch to value capture once the different firms manage to establish innovations as the dominant technology. Along with the technologies, regulations are also established, which reduces uncertainty for stakeholders. This dissertation focus solely on the early stages of innovations. Analysing the market and non-market behaviour of stakeholders by taking into account the dynamic aspects of technologies and the evolution of regulation is an interesting avenue for future research.

Throughout this research, we examined different strategies used by stakeholders to eliminate barriers that could hinder the development of innovations. However, we did not compare the effectiveness and feasibility of these strategies. While the development of some of the strategies requires high investments for public actors, such as the installment of infrastructure or the provision of subsidies, others require high acceptance of the general public, like taxes on gas prices. Further research could focus on performing a cost-benefit analysis of the different strategies to determine the most efficient measure to implement.

The evolution of electric and autonomous vehicles will spawn many opportunities for value creation, and will create diverse business models. An analysis of the sustainability and efficiency of the different business models is an interesting research question to explore. Additionally, many of the business models that are appearing put the user at the center. Therefore, another key question to explore is the input of users regarding the technologies, the intrinsic motivations that lead them to choose between technologies and how to shape their behaviour to increase the acceptability and scalability of technologies.

Another issue that is mentioned but not widely explored in this research is the justification for public intervention. Public actors have taken an active role in integrating innovations in mobility. Their intervention could be judged necessary to favor the best technology in the market. The justifications, mechanisms and output from their intervention is a question that can be further analyzed in the context of competing technologies.

Finally, in parallel to electric and autonomous vehicles, other types of innovations in mobility, such as hydrogen vehicles, are emerging in the market. Despite the EU has made a clear choice to support BEVs for the decarbonisation of personal light-duty transport, hydrogen vehicles are still a possible solution for heavy-duty vehicles and other types of transport modes. Stakeholders that participate in electric and autonomous vehicle's scaling-up have also ongoing projects to improve hydrogen vehicle's technology. Alongside, new stakeholders, namely startups, are engaging solely in the research and development of hydrogen vehicles. In this market, we observe similar patterns of ecosystem formation among stakeholders with diverging interests, infrastructure needs and regulation issues. An example is the consortium Hydrogen Europe, which has the objective to accelerate the European hydrogen industries and comprises 315 companies, among which Airbus, Audi, BMW, BP, and Spanish utility company Iberdrola. New research questions can emerge in this context, for example concerning the decision to enter in the different markets, and how stakeholders push forward and privilege either one or both of the substituting technologies.

APPENDIX A

APPENDICES OF CHAPTER 2

Table A.1: Cross-correlation table

	1	2	3	4	5	6	7	8	9	10	11	12
1. DepVar												
2. Bottleneck component	0.03**											
3. Firm age	0.05***	0.20***										
4. Connectedness	0.07***	0.05***	0.17***									
5. Trademarks	0.06***	-0.05***	0.30***	0.07***								
6. Patents	0.02*	0.16***	0.61***	0.08***	0.21***							
7. Industry overlap	0.01	0.05***	0.03***	0.01	-0.00	0.03**						
8. Geographical distance	-0.02**	0.00	-0.00	0.01	0.00	0.00	0.01					
9. Silicon Valley	0.05***	0.01	-0.02*	0.10***	-0.02*	0.03**	-0.02*	0.03**				
10. Startup experience	0.01	-0.09***	-0.06***	0.08***	0.09***	0.02*	0.00	0.01	-0.04***			
11. VC arm	0.03**	0.00	0.00	-0.00	0.00	0.00	-0.04***	-0.37***	0.00	0.00		
12. CVC/IVC ratio	0.01	-0.08***	-0.13***	-0.03***	0.14***	0.04***	0.01	-0.00	0.07***	-0.10***	-0.00	

Table A.2: Regression results excluding independent variables

	Dependent variable: tie formation				
	excluding bottleneck	*excluding firm age*	*excluding connectedness*	*excluding trademarks*	*excluding inf. defenses*
	(1)	(2)	(3)	(4)	(5)
Bottleneck component	-	0.441***	0.495***	0.418**	0.471***
		(0.170)	(0.170)	(0.171)	(0.170)
Firm age	0.169***	-	0.166***	0.164***	-
	(0.029)		(0.028)	(0.029)	
Connectedness	2.501***	2.579***	-	2.383***	-
	(0.556)	(0.575)		(0.555)	
Trademarks	−0.008	−0.009	−0.017	-	-
	(0.018)	(0.018)	(0.018)		
Patents	0.010**	0.014***	0.017***	0.009**	0.018***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)
Industry overlap	0.329	0.296	0.310	0.309	0.295
	(0.201)	(0.201)	(0.201)	(0.201)	(0.200)
Geographical distance	−0.002*	−0.002**	−0.002*	−0.002*	−0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Silicon Valley	0.855***	0.821***	0.988***	0.870***	0.957***
	(0.163)	(0.163)	(0.161)	(0.164)	(0.160)
Startup experience	0.048	0.104	0.129*	0.078	0.154**
	(0.072)	(0.075)	(0.070)	(0.074)	(0.071)
VC arm	0.374**	0.371**	0.373**	0.373**	0.371**
	(0.172)	(0.172)	(0.171)	(0.172)	(0.171)
CVC/IVC ratio	0.897	3.367	1.482	1.359	3.018
	(2.223)	(2.230)	(2.159)	(2.219)	(2.103)
Constant	−5.844***	−6.281***	−6.145***	−6.112***	−6.196***
	(0.637)	(0.661)	(0.636)	(0.651)	(0.632)
Observations	13,869	13,869	13,869	13,869	13,869
Akaike Inf. Crit.	1,671	1,690	1,680	1,666	1,705
Note:					*p<0.1; **p<0.05; ***p<0.01

APPENDIX B

APPENDICES OF CHAPTER 3

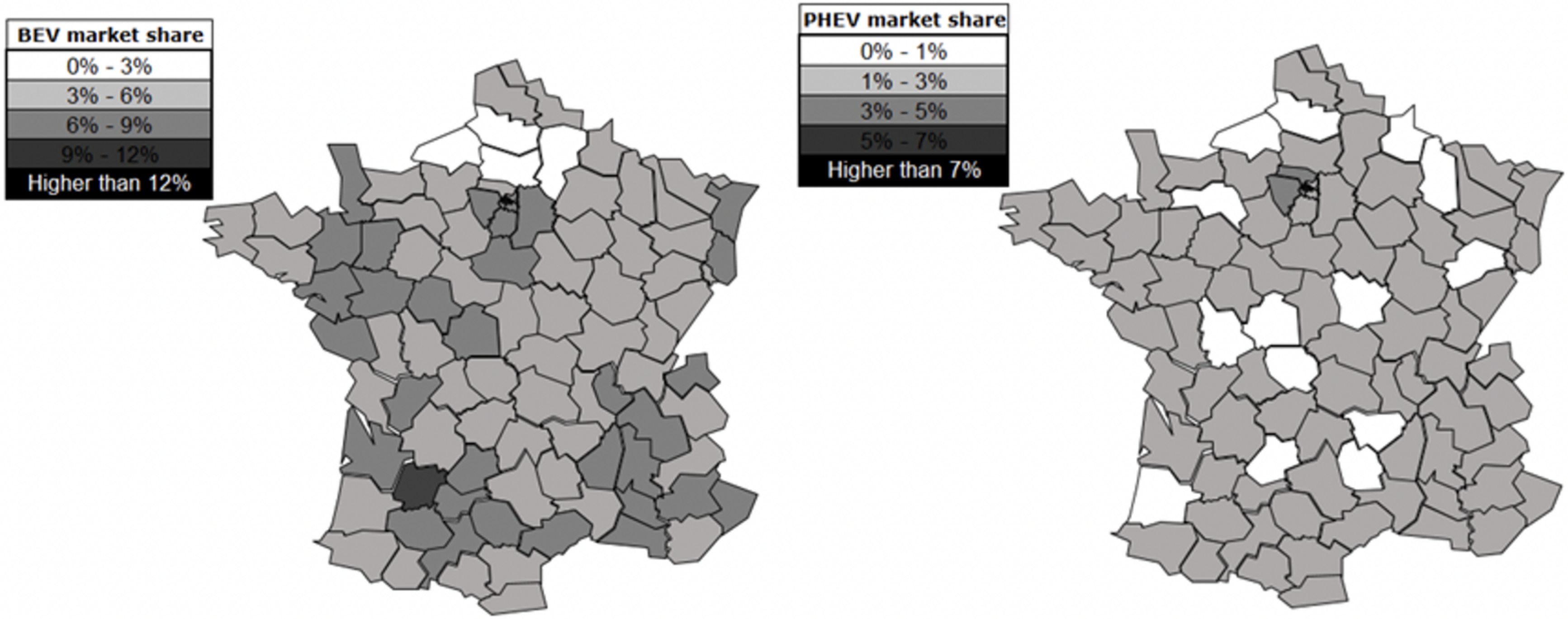

Figure B.1: Evolution percentage of the BEV (Left) and PHEV (Right) market shares in 95 French departments between 2015 and 2019

Table B.1: Variable correlation coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1. Log(BEV MS)																											
2. Log(PHEV MS)	0.52***																										
3. Log slow&normal charg den	0.35***	0.64***																									
4. Density of slow chargers	0.25***	0.32***	0.49***																								
5. Density of normal chargers	0.30***	0.43***	0.68***	0.93***																							
6. Density of fast chargers	0.31***	0.43***	0.70***	0.83***	0.92***																						
7. Density of ultrafast chargers	0.17***	0.30***	0.50***	0.35***	0.54***	0.48***																					
8. Difference in taxes	0.24***	0.26***	0.23***	0.09	0.13**	0.16***	0.11*																				
9. Number of models BEV	0.43***	0.47***	0.34***	0.07	0.13**	0.14**	0.12*	0.18***																			
10. Number of models PHEV	0.41***	0.49***	0.40***	0.07	0.13**	0.15**	0.12**	0.21***	0.98***																		
11. Subsidies BEV	0.25***	0.38***	0.59***	0.40***	0.54***	0.50***	0.38***	0.18***	0.19***	0.20***																	
12. Subsidies PHEV	0.22***	0.34***	0.52***	0.30***	0.44***	0.39***	0.34***	0.17***	0.20***	0.21***	0.97***																
13. Bonus BEV	0.22***	0.08	-0.07	0.31***	0.24***	0.21***	0.05	-0.05	0.49***	0.40***	0.13**	0.13**															
14. Bonus PHEV	-0.05	-0.22***	-0.53***	-0.05	-0.11*	-0.13**	-0.09	-0.19***	-0.04	-0.15**	-0.10*	-0.05	0.59***														
15. VKT	-0.00	0.02	-0.14**	-0.20***	-0.24***	-0.23***	-0.19***	-0.14**	0.00	0.00	-0.04	-0.01	-0.05	0.01													
16. Vehicle's elec range BEV	-0.01	0.02	0.03	0.06	0.05	0.04	0.01	0.02	-0.00	-0.00	-0.00	-0.01	0.11*	-0.05	-0.07												
17. Vehicle's elec range PHEV	0.29***	0.26***	0.14**	-0.00	0.02	0.03	0.01	0.10*	0.62***	0.59***	0.06	0.08	0.36***	0.01	0.06	-0.06											
18. Parking at home	-0.19***	-0.50***	-0.50***	-0.18***	-0.30***	-0.32***	-0.24***	-0.02	0.00	0.00	-0.36***	-0.33***	-0.02	-0.01	-0.06	0.03	0.07										
19. Two vehicles	-0.15**	-0.43***	-0.62***	-0.54***	-0.67***	-0.66***	-0.51***	-0.11*	-0.00	-0.00	-0.52***	-0.44***	-0.11*	0.00	0.25***	-0.03	0.09*	0.50***									
20. Emissions	-0.13**	-0.47***	-0.52***	-0.25***	-0.38***	-0.39***	-0.31***	-0.11*	0.00	0.00	-0.36***	-0.33***	-0.03	0.00	0.06	0.02	0.06	0.77***	0.53***								
21. Solar Production	0.05	-0.10*	-0.18***	-0.08	-0.12*	-0.08	-0.11*	0.04	0.08	0.08	-0.17***	-0.15**	-0.00	-0.04	0.18***	-0.02	0.12**	0.44***	0.22***	0.51***							
22. Income	0.30***	0.55***	0.55***	0.49***	0.59***	0.52***	0.32***	0.12*	0.01	0.01	0.47***	0.41***	0.09*	-0.01	-0.14**	0.01	-0.08	-0.56***	-0.52***	-0.60***	-0.31***						
23. Unemployment rate	-0.29***	-0.22***	-0.17***	-0.12**	-0.14**	-0.11*	-0.10*	-0.27***	-0.29***	-0.31***	-0.12*	-0.10*	-0.02	0.18***	0.15**	0.06	-0.14**	-0.18***	-0.17***	-0.04	0.07	-0.37***					
24. Population density	0.22***	0.39***	0.61***	0.77***	0.84***	0.81***	0.48***	0.14**	0.00	0.00	0.46***	0.36***	0.17***	-0.01	-0.29***	0.03	-0.07	-0.31***	-0.79***	-0.41***	-0.14**	0.61***	-0.09				
25. Education	0.37***	0.53***	0.54***	0.47***	0.56***	0.53***	0.34***	0.09*	0.00	0.00	0.40***	0.35***	0.07	0.00	-0.01	-0.03	-0.08	-0.55***	-0.58***	-0.55***	-0.12*	0.84***	-0.23***	0.60***			
26. p20-39	0.12**	0.46***	0.55***	0.38***	0.49***	0.51***	0.36***	0.08	-0.04	-0.04	0.46***	0.41***	0.07	0.03	-0.06	0.02	-0.11*	-0.72***	-0.69***	-0.67***	-0.45***	0.71***	-0.02	0.57***	0.69***		
27. p40-59	-0.24***	-0.35***	-0.38***	-0.17***	-0.20***	-0.23***	-0.14**	-0.14**	-0.29***	-0.31***	-0.06	-0.04	-0.04	0.19***	0.12**	-0.07	-0.11*	0.39***	0.47***	0.33***	0.23***	-0.10*	-0.08	-0.22***	-0.18***	-0.42***	
28. Female	0.21***	0.29***	0.23***	0.28***	0.31***	0.28***	0.18***	-0.04	-0.01	-0.01	0.09*	0.06	0.06	0.02	-0.03	-0.00	-0.03	-0.37***	-0.49***	-0.27***	0.01	0.19***	0.31***	0.33***	0.31***	0.14**	-0.39***

Note: [*]p<10%; [**]p<5%; [***]p<1%

Table B.2: Sensitivity of regression results for models against the exclusion of departments

	Dependent variable:			
	Log BEV Market Share		Log PHEV Market Share	
	(1)	(2)	(3)	(4)
Log Slow and Normal Chargers Density	-0.029^{*}	-0.019	0.064^{***}	0.070^{***}
	(0.017)	(0.018)	(0.020)	(0.020)
Log Fast Chargers Density	7.100^{***}	6.089^{**}		
	(2.550)	(2.587)		
Log Ultra-Fast Chargers Density	4.865^{**}	4.618^{**}		
	(2.008)	(1.994)		
Log Subsidies/Vehicle price	1.047^{***}	0.984^{**}	-1.295	-0.460
	(0.401)	(0.436)	(1.395)	(1.431)
Log Bonus/Vehicle price	1.698	1.904	-0.930^{**}	-0.829^{*}
	(1.720)	(1.798)	(0.439)	(0.451)
Difference in Registration Tax	0.003^{***}	0.003^{***}		
	(0.001)	(0.001)		
Number of Models	0.020^{***}	0.021^{***}	0.009^{***}	0.011^{***}
	(0.005)	(0.006)	(0.002)	(0.002)
Log Electricity price/SP95 price	-1.457^{***}	-1.631^{***}	-4.177^{***}	-4.388^{***}
	(0.336)	(0.370)	(0.463)	(0.483)
VKT	0.003	0.009	0.018	0.017
	(0.011)	(0.012)	(0.013)	(0.013)
Vehicle's electric range	-0.002	-0.002	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Parking at home	-0.159	-0.091	-0.321^{***}	-0.192
	(0.100)	(0.111)	(0.119)	(0.117)
Two Vehicles	0.014	0.008	-0.011	-0.010
	(0.010)	(0.010)	(0.012)	(0.011)
Emissions	0.002	0.001	-0.002	-0.003^{**}
	(0.001)	(0.001)	(0.001)	(0.001)
Solar Production	-0.131	-0.154	0.413^{***}	0.328^{**}
	(0.108)	(0.116)	(0.135)	(0.128)
Income	0.00001	0.00001	0.00005^{**}	0.0001^{***}
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Unemployment	0.011	0.011	-0.059^{**}	-0.036
	(0.020)	(0.022)	(0.024)	(0.024)
Population density	0.00001	-0.00001	-0.00004	-0.00004^{*}
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Education	7.337^{***}	7.325^{***}	-2.245	-2.658
	(2.070)	(2.244)	(2.470)	(2.359)
p20-39	-6.131^{***}	-5.085^{**}	-0.156	-0.653
	(2.015)	(2.287)	(2.465)	(2.492)
p40-59	-13.015^{***}	-12.113^{***}	-7.323	-4.639
	(3.887)	(4.153)	(5.033)	(4.832)
Female	-0.022	0.013	0.090	0.108
	(0.075)	(0.081)	(0.092)	(0.088)
Constant	-4.127	-6.597	-16.834^{***}	-19.102^{***}
	(4.634)	(4.947)	(5.817)	(5.560)
Observations	470	380	469	379
Conditional R2	0.848	0.862	0.855	0.847
Marginal R2	0.438	0.502	0.657	0.706

Note: *p**p***p<0.01

Table B.3: Sensitivity of regression results for models against the exclusion of big cities

	Dependent variable:			
	Log BEV Market Share		Log PHEV Market Share	
	(1)	(2)	(3)	(4)
Log Slow and Normal Chargers Density	-0.029*	-0.026	0.064***	0.073***
	(0.017)	(0.019)	(0.020)	(0.020)
Log Fast Chargers Density	7.100***	5.218		
	(2.550)	(3.211)		
Log Ultra-Fast Chargers Density	4.865**	4.953**		
	(2.008)	(2.010)		
Log Subsidies/Vehicle price	1.047***	1.055**	-1.295	-1.563
	(0.401)	(0.426)	(1.395)	(1.460)
Log Bonus/Vehicle price	1.698	2.380	-0.930**	-0.935**
	(1.720)	(2.558)	(0.439)	(0.449)
Difference in Registration Tax	0.003***	0.003***		
	(0.001)	(0.001)		
Number of Models	0.020***	0.018**	0.009***	0.010***
	(0.005)	(0.007)	(0.002)	(0.002)
Log Electricity price/SP95 price	-1.457***	-1.490***	-4.177***	-4.225***
	(0.336)	(0.348)	(0.463)	(0.471)
VKT	0.003	0.006	0.018	0.014
	(0.011)	(0.012)	(0.013)	(0.013)
Vehicle's electric range	-0.002	-0.002	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Parking at home	-0.159	-0.141	-0.321***	-0.302***
	(0.100)	(0.102)	(0.119)	(0.114)
Two Vehicles	0.014	0.025**	-0.011	-0.015
	(0.010)	(0.011)	(0.012)	(0.013)
Emissions	0.002	0.002	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Solar Production	-0.131	-0.144	0.413***	0.411***
	(0.108)	(0.110)	(0.135)	(0.130)
Income	0.00001	0.00001	0.00005**	0.00005***
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Unemployment	0.011	0.014	-0.059**	-0.054**
	(0.020)	(0.020)	(0.024)	(0.023)
Population density	0.00001	0.0001*	-0.00004	-0.0001
	(0.00002)	(0.00004)	(0.00002)	(0.00004)
Education	7.337***	7.586***	-2.245	-2.093
	(2.070)	(2.101)	(2.470)	(2.343)
p20-39	-6.131***	-5.961***	-0.156	0.080
	(2.015)	(2.072)	(2.465)	(2.335)
p40-59	-13.015***	-15.565***	-7.323	-5.582
	(3.887)	(4.250)	(5.033)	(5.058)
Female	-0.022	0.002	0.090	0.083
	(0.075)	(0.078)	(0.092)	(0.089)
Constant	-4.127	-5.346	-16.834***	-16.882***
	(4.634)	(4.787)	(5.817)	(5.625)
Observations	470	455	469	454
Conditional R2	0.848	0.842	0.855	0.835
Marginal R2	0.438	0.418	0.657	0.647
Note:				*p**p***p<0.01

Table B.4: Sensitivity of regression results for models against the exclusion of charging infrastructure control variables

	Dependent variable:			
	Log BEV Market Share		Log PHEV Market Share	
	(1)	(2)	(3)	(4)
Log Slow and Normal Chargers Density	-0.029*		0.064***	
	(0.017)		(0.020)	
Log Fast Chargers Density	7.100***			
	(2.550)			
Log Ultra-Fast Chargers Density	4.865**			
	(2.008)			
Log Subsidies/Vehicle price	1.047***	1.379***	-1.295	0.017
	(0.401)	(0.364)	(1.395)	(1.321)
Log Bonus/Vehicle price	1.698	3.441**	-0.930**	-1.518***
	(1.720)	(1.378)	(0.439)	(0.396)
Difference in Registration Tax	0.003***	0.003***		
	(0.001)	(0.001)		
Number of Models	0.020***	0.016***	0.009***	0.011***
	(0.005)	(0.005)	(0.002)	(0.002)
Log Electricity price/SP95 price	-1.457***	-1.805***	-4.177***	-3.845***
	(0.336)	(0.304)	(0.463)	(0.447)
VKT	0.003	0.001	0.018	0.021*
	(0.011)	(0.011)	(0.013)	(0.013)
Vehicle's electric range	-0.002	-0.003	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Parking at home	-0.159	-0.142	-0.321***	-0.391***
	(0.100)	(0.098)	(0.119)	(0.115)
Two Vehicles	0.014	0.014	-0.011	-0.016
	(0.010)	(0.010)	(0.012)	(0.011)
Emissions	0.002	0.001	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Solar Production	-0.131	-0.092	0.413***	0.436***
	(0.108)	(0.107)	(0.135)	(0.133)
Income	0.00001	0.00001	0.00005**	0.0001***
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Unemployment	0.011	0.006	-0.059**	-0.074***
	(0.020)	(0.019)	(0.024)	(0.023)
Population density	0.00001	0.00001	-0.00004	-0.00003
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Education	7.337***	6.701***	-2.245	-2.354
	(2.070)	(2.047)	(2.470)	(2.423)
p20-39	-6.131***	-5.151***	-0.156	-1.852
	(2.015)	(1.969)	(2.465)	(2.363)
p40-59	-13.015***	-10.354***	-7.323	-11.656**
	(3.887)	(3.776)	(5.033)	(4.763)
Female	-0.022	0.013	0.090	0.050
	(0.075)	(0.074)	(0.092)	(0.090)
Constant	-4.127	-7.393*	-16.834***	-12.459**
	(4.634)	(4.494)	(5.817)	(5.552)
Observations	470	470	469	469
Conditional R2	0.848	0.831	0.855	0.857
Marginal R2	0.438	0.438	0.657	0.667

Note: *p**p***p<0.01

APPENDIX C

APPENDICES OF CHAPTER 4

C.1 Non-market networks divided by firms' sector

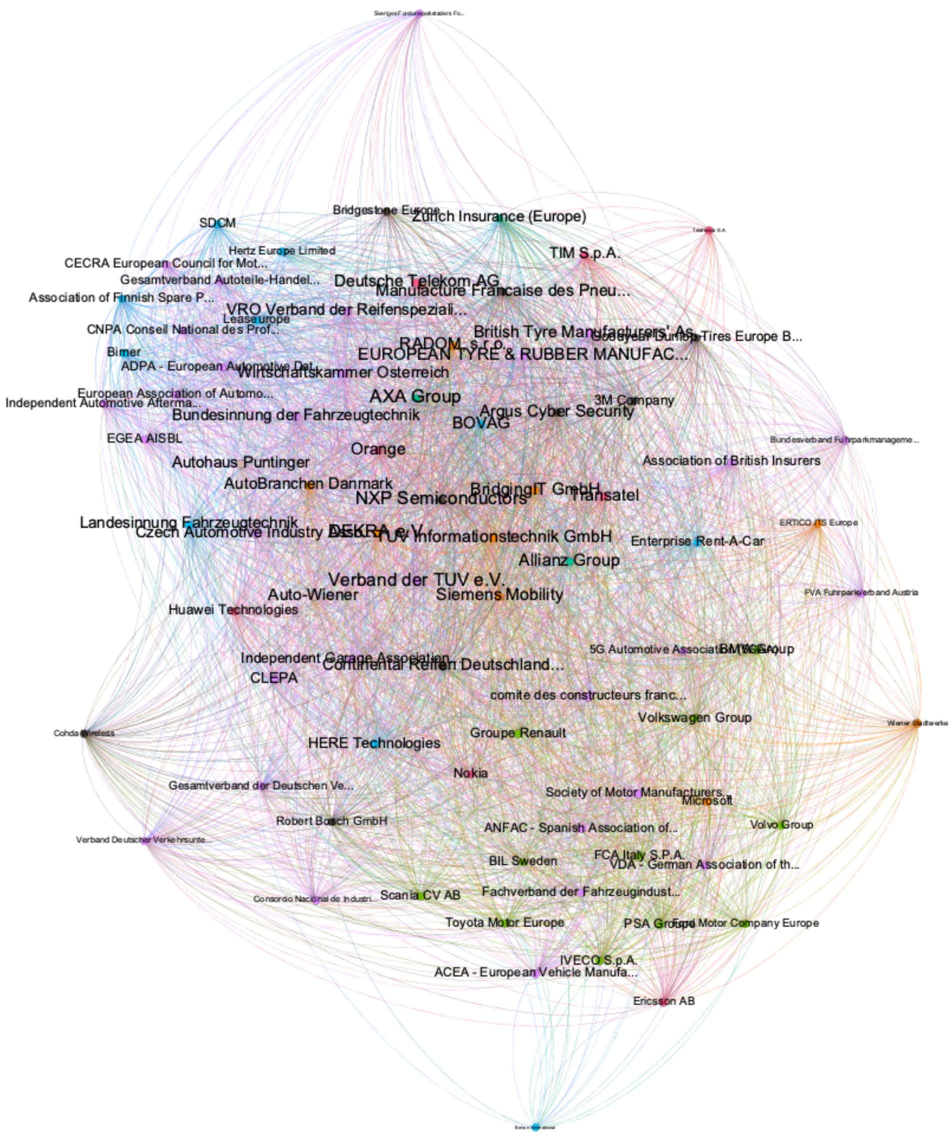

Figure C.1: Cybersecurity network

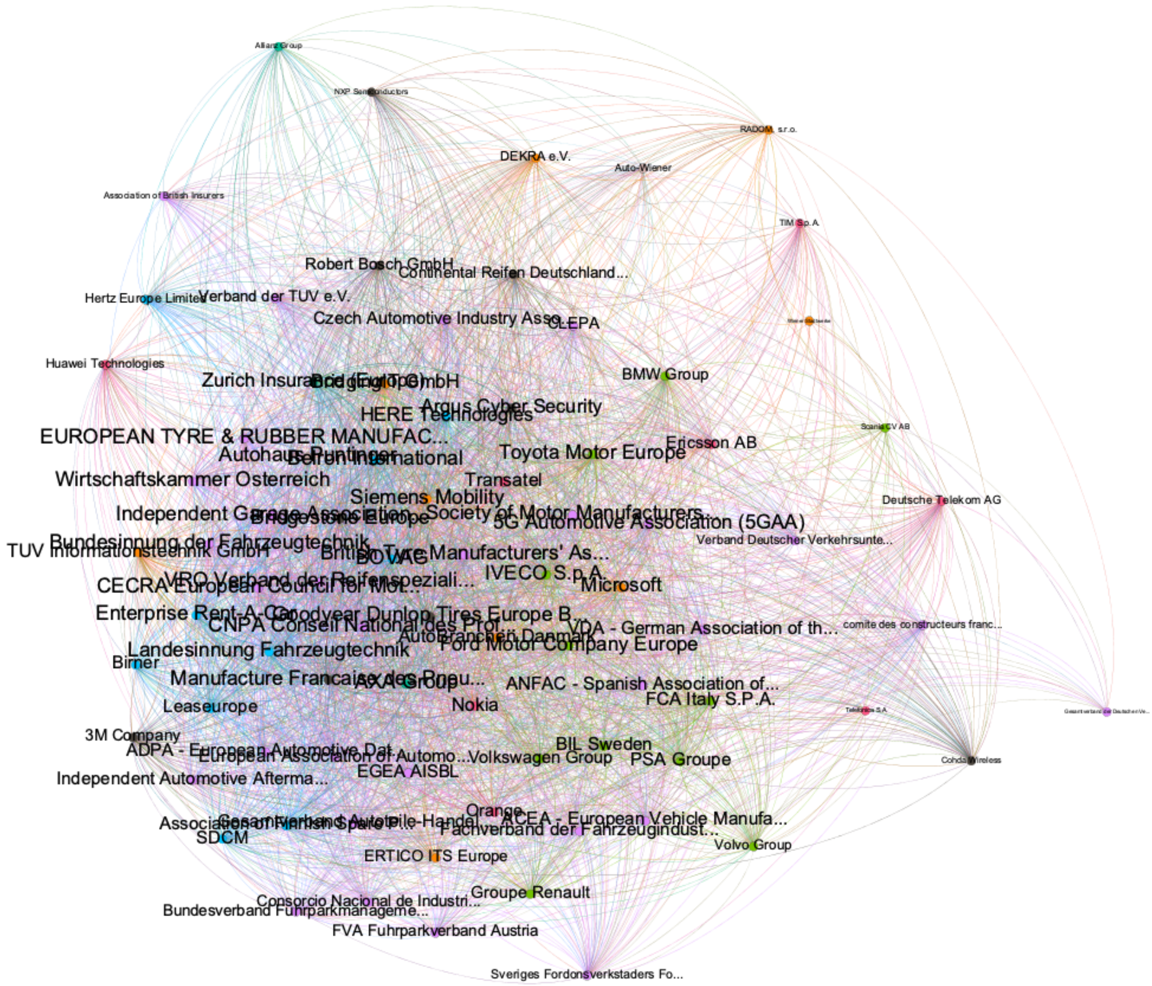

Figure C.2: Data protection & governance network

C.2 Network Statistics

Table C.1: Cybersecurity Network Statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
degree	82	70.537	11.431	22	65.2	80	80
weighted.degree	82	160.220	45.830	22	149	198	232
Eccentricity	82	2.024	0.155	2	2	2	3
closnesscentrality	82	0.897	0.098	0.574	0.837	0.988	0.988
harmonicclosnesscentrality	82	0.935	0.071	0.634	0.903	0.994	0.994
betweenesscentrality	82	5.244	3.773	0.000	2.211	9.105	9.906
Authority	82	0.109	0.017	0.033	0.104	0.122	0.122
Hub	82	0.109	0.017	0.033	0.104	0.122	0.122
modularity_class	82	0.976	0.860	0	0	2	2
componentnumber	82	0.000	0.000	0	0	0	0
clustering	82	0.930	0.046	0.883	0.883	0.975	1.000
triangles	82	2,312.890	565.630	231	2,069.5	2,790	2,790
eigencentrality	82	0.896	0.136	0	0.9	1	1
pageranks	82	0.012	0.002	0.005	0.011	0.014	0.014

Table C.2: Data Protection & Governance Network Statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
degree	82	71.634	12.973	10	73	77	80
weighted.degree	82	202.610	69.910	13	188.8	260	271
Eccentricity	82	2.000	0.000	2	2	2	2
closnesscentrality	82	0.909	0.093	0.533	0.910	0.953	0.988
harmonicclosnesscentrality	82	0.942	0.080	0.562	0.951	0.975	0.994
betweenesscentrality	82	4.683	3.943	0.044	2.271	7.452	17.361
Authority.data	82	0.109	0.020	0.014	0.113	0.117	0.118
Hub.data	82	0.109	0.020	0.014	0.113	0.117	0.118
modularity_class	82	1.183	0.772	0	1	2	2
componentnumber	82	0.000	0.000	0	0	0	0
clustering	82	0.945	0.027	0.856	0.930	0.953	0.995
triangles	82	2,469.622	620.001	42	2,563.2	2,776	2,840
eigencentrality	82	0.917	0.169	0.116	0.949	0.988	1.000
pageranks	82	0.012	0.002	0.003	0.012	0.013	0.014

C.3 Non-Market Networks divided by divided by clusters

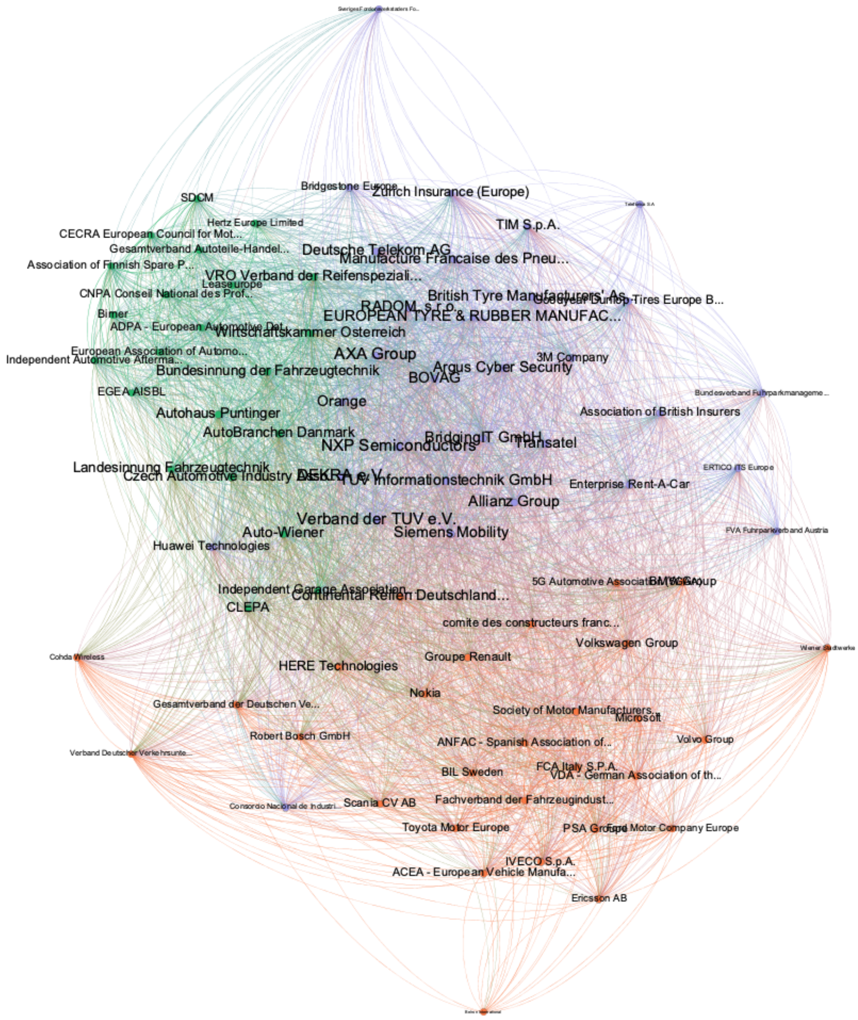

Figure C.3: Cybersecurity network divided by clusters

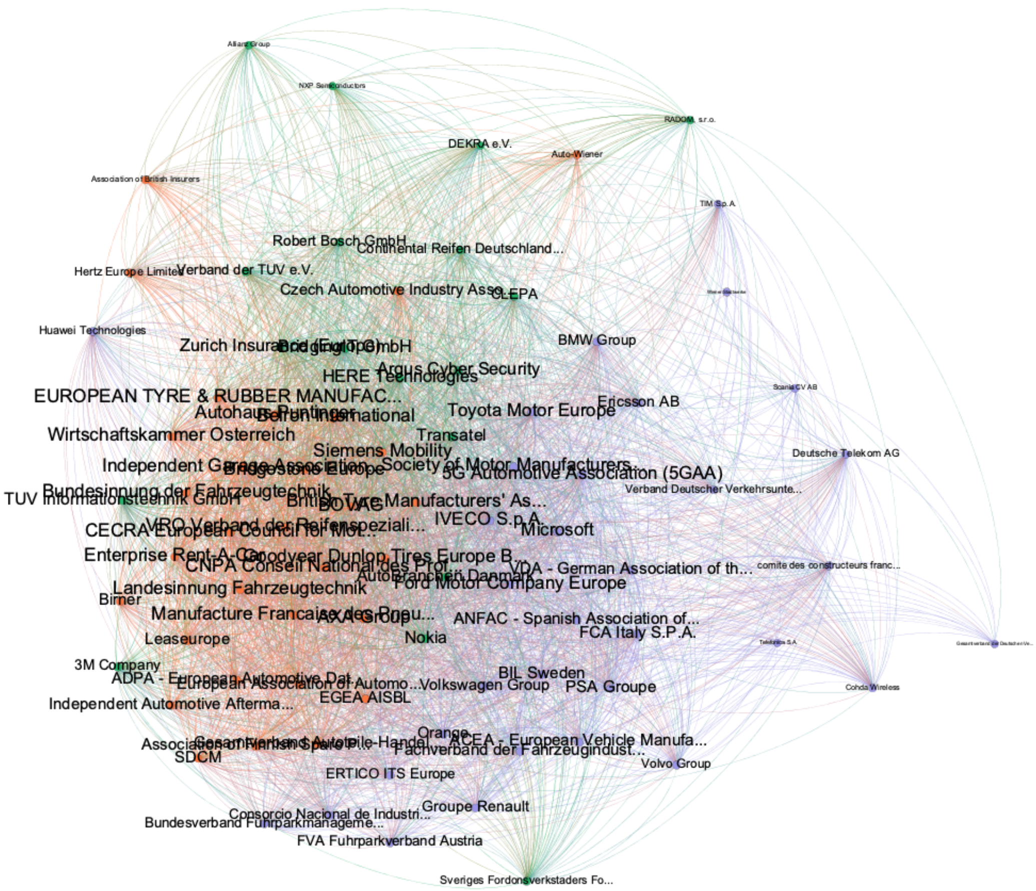

Figure C.4: Data protection & governance network divided by clusters

C.4 Summary Statistics

Table C.3: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
lobbying.alignment.cybersecurity	3,321	1.978	1.367	0	1	3	5
lobbying.alignment.dataprotection	3,321	2.501	1.414	0	1	4	5
ecosystem.alignment	3,321	0.061	0.238	0	0	0	1
trade.partnership	3,321	0.063	0.242	0	0	0	1
partnership	3,321	0.133	0.339	0	0	0	1
sector.alignment	3,321	0.192	0.394	0	0	0	1
samecountry	3,321	0.093	0.291	0	0	0	1
samesize	3,321	0.251	0.434	0	0	1	1
both.in.TR	3,321	0.533	0.499	0	0	1	1

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RÉSUMÉ

Les véhicules électriques (VE) et autonomes (VA) ont pris de l'ampleur au cours de la dernière décennie car ils sont une source de création de valeur et peuvent apporter une solution à diverses externalités négatives dans le secteur du transport. Néanmoins, ces technologies peinent à atteindre un marché de masse et à se faire accepter dans les environnements marchands et non marchands. Plusieurs facteurs influencent leur diffusion tardive : tout d'abord, les entreprises membres des écosystèmes des VE et VA sont certes interdépendantes, mais elles ont des intérêts différents et parfois contradictoires, cela pouvant générer des problèmes de coopétition qui peuvent affecter leur développement. Deuxièmement, ces technologies nécessitent des changements d'infrastructure importants, pour lesquels les acteurs du marché doivent supporter d’importants coûts irrécupérables. Enfin, les réglementations ne sont pas encore adaptées à l'introduction et au maintien des technologies sur le marché. Les acteurs de l'écosystème sont conscients de ces barrières et emploient ainsi diverses stratégies pour accroître la part de ces technologies sur le marché. Cette thèse explore les stratégies utilisées par les acteurs privés et publics pour surmonter les défis de du développement en grande échelle des VE et VA. Le premier article analyse les mécanismes qui équilibrent la coopération et la concurrence dans le contexte de l'écosystème VA. Les acteurs privés utilisent des mécanismes comme (i) les investissements CVC (i.e. capital-risque d’entreprise) pour résoudre les goulots d'étranglement et (ii) les mécanismes de protection de la propriété intellectuelle pour éviter les problèmes d'appropriation illicite. Le deuxième article analyse les facteurs techniques, économiques et socio-démographiques qui influencent les achats de VE. L'installation d'une infrastructure de recharge et les incitations financières, entre autres, sont des facteurs déterminants pour accroître l'adoption des VE. Le troisième article analyse le comportement non marchand des entreprises lorsqu'elles coopèrent sur le marché, au travers de la création d'écosystèmes. Les entreprises ont tendance à aligner les stratégies marchandes et non marchandes pour résoudre les obstacles réglementaires.

MOTS CLÉS

Véhicules électriques, Véhicules autonomes, Écosystèmes, Coopétition, Stratégies hors-marché

ABSTRACT

Electric (EV) and autonomous vehicle (AV) technologies have gained momentum in the past decade since they are a source of value creation and may provide a solution to a variety of transportation's negative externalities. Regardless, they struggle to reach a mass market and gain acceptance in the market and non-market environments. Several factors influence their lagged diffusion. First, firms participating in the EV and AV ecosystems are interdependent but have different and sometimes conflicting interests, which could potentially lead to coopetition issues in their development. Second, the technologies require significant infrastructure changes, for which market participants must endure high sunk costs. Third, regulations are still not adapted to introduce and sustain the technologies in the market. Ecosystem actors are aware of these barriers and employ various strategies to address each of the upscaling issues. This thesis explores the strategies used by private and public actors to overcome the upscaling challenges of EVs and AVs. The first paper analyses the mechanisms that balance cooperation and competition in the AV ecosystem context. Private actors use mechanisms like CVC investments to resolve bottlenecks and IP protection mechanisms to avoid misappropriation issues. The second paper analyses technical, economic and socio-demographic factors that influence EV purchases. The installation of charging infrastructure and financial incentives, among others are determinants to increasing EV adoption. The third paper analyses the non-market behaviour of firms when they cooperate in the market environment through the creation of ecosystems. Firms tend to align market and non-market strategies to resolve regulatory barriers.

KEYWORDS

Electric vehicles, Autonomous Vehicles, Ecosystems, Coopetition, Non-market Strategies